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Exponent

**Field Sampling and Analysis
Plan:
Avtex Fibers Superfund Site,
Operable Unit 7**

Prepared for

FMC Corporation
Philadelphia, Pennsylvania

AR301883

Exponent

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Operable Unit 7**

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1. Introduction

This Field Sampling and Analysis Plan (FSAP) has been prepared for the supplemental field investigation of Operable Unit 7 (OU-7) of the Avtex Fibers Superfund site (Avtex site), as described in Section 6 of the Feasibility Study (FS) Work Plan; Exponent 2000). Operable Unit 7 includes viscose basins 9, 10, and 11, site groundwater, and surface water, as defined in the Consent Decree between the U.S. Environmental Protection Agency Region III (EPA) and FMC Corporation (FMC; U.S. EPA 1999a). The site background is detailed in Section 2 of the FS Work Plan—including a site description; an overview of historical operations at the site; a summary of the site's regulatory and environmental history; and a discussion of the climate, hydrology, and surface-water hydrology at the site. This FSAP covers the collection and analysis of groundwater samples from 16 monitoring wells identified as the monitoring well network for viscose basins 1–8 and the new landfill (OU-10).

This field investigation is being conducted to fill the data gaps identified in Section 5 of the FS Work Plan for OU-7. Four primary activities will be performed during the supplemental field investigation: 1) groundwater monitoring well and temporary wellpoint installation, 2) sampling of aqueous and solid media, 3) collection of synoptic water-level measurements, and 4) field testing. These activities will be conducted in two phases, as discussed in Section 6 (summarized in Table 6-1) of the FS work plan. The Phase I investigation will focus on characterization of site groundwater, and will include:

- Installation of groundwater monitoring wells
- Installation of Geoprobe® temporary wellpoints
- Groundwater sampling of existing and proposed wells/wellpoints
- Performance of a well survey.

The second phase of the field investigation will focus on the chemistry and hydrology of viscose basins 9, 10, and 11, and will include:

- Installation of boreholes and temporary wellpoints in viscose basins 9, 10, and 11 using a hollow-stem auger drill rig
- Installation of overburden temporary wellpoints adjacent to viscose basins 9, 10, and 11 using a hollow-stem auger drill rig
- Infiltration-rate testing on the surface of viscose basins 9, 10, and 11
- Single-well pumping tests in overburden and waste viscose temporary wellpoints

- Site-wide measurement of groundwater levels
- Geologic mapping
- Collection of waste viscose samples and laboratory testing of these materials
- Collection of pore-water samples from temporary wellpoints in viscose basins 9, 10, and 11
- Installation of deep bedrock monitoring well 343, if necessary (see Section 3.4.4).

This FSAP presents the monitoring well and wellpoint locations and installation techniques, the sampling locations and procedures for aqueous and solid media, the field and laboratory testing procedures, and the analytical methods that will be used during the investigation. All field work and laboratory work will be conducted per the *Quality Assurance Project Plan (QAPP) Supplement for the Remedial Investigation/Feasibility Study, Avtex Fibers Site, Front Royal, Virginia* (ERM 1999), the *Site-wide Health and Safety Plan (HASP), Avtex Fibers Superfund Site, Front Royal, Virginia* (FMC 1999), and the HASP addendum for implementing this FSAP (Attachment A-1), unless otherwise specified in this document.

2. Objectives

Detailed sampling objectives for the supplemental field investigation are presented in Sections 5 and 6 of the FS Work Plan. The following is a general summary of the objectives for each of the primary activities to be performed during the investigation, including the data quality objectives.

2.1 Groundwater Monitoring Well and Temporary Wellpoint Installation

A total of 8 or 9 groundwater monitoring wells, 14 Geoprobe® temporary wellpoints, and 14 viscose basin and overburden temporary wellpoints will be installed during the supplemental field investigation. The groundwater monitoring wells and Geoprobe® wellpoints will be installed to meet the following objectives:

- Characterize potential sources of groundwater contaminants in the plant area
- Characterize groundwater quality downstrike of viscose basins 1–8 and the new landfill.
- Provide additional background water quality data
- Characterize the downstrike extent of the plume.

The viscose basin and overburden temporary wellpoints will be installed to meet the following objectives:

- Provide water levels within the basins and in the overburden adjacent to viscose basins 9, 10, and 11
- Characterize pore water within viscose basins 9, 10, and 11
- Provide estimates of horizontal hydraulic conductivity in the waste viscose in the basins
- Improve estimates of horizontal hydraulic conductivity in the overburden
- Collect samples of viscose basin pore water for laboratory experiments.

2.2 Sampling Aqueous and Solid Media

The supplemental field investigation will include collection of samples of groundwater/pore water and viscose basin solids. A total of 75 groundwater monitoring wells, 14 Geoprobe[®] temporary wellpoints, and 9 viscose basin temporary wellpoints will be sampled during the supplemental field investigation. These efforts will provide data to meet the following objectives:

- Characterize potential sources of groundwater contaminants in the plant area
- Characterize pore water from viscose basins 9, 10, and 11
- Provide additional background water quality data
- Characterize groundwater quality downstrike of viscose basins 1–8 and the new landfill.
- Determine the current spatial extent and magnitude of groundwater contamination
- Characterize the downstrike extent of the plume
- Collect samples of groundwater for laboratory experiments
- Quantify parameters that will affect the transport and fate of site chemicals (e.g., density of the DAPL)
- Quantify parameters to evaluate the feasibility of various remediation technologies (e.g., identify chemicals that could cause well fouling).

Samples of waste viscose and of the overburden material underlying the basins will be collected from viscose basins 9, 10, and 11 to provide data to meet the following objectives:

- Characterize hydrologic parameters for use in estimating recharge rates to the viscose basins
- Obtain data to improve the understanding of the vertical hydraulic conductivity of the waste viscose and overburden
- Obtain data to evaluate the potential for compaction (i.e., settling) and release of pore water from the waste viscose that may result from placement of an engineered cap over the viscose basins
- Characterize the concentrations of site chemicals currently within the waste viscose material that could be released to groundwater
- Collect samples for use in laboratory treatability tests to evaluate the efficacy of chemical oxidation, vermiculture, and direct electrical

resistance heating (ERH) treatment technologies, as well as the use of physical and chemical techniques to improve waste viscose handling characteristics.

2.3 Field Tests

Two field tests will be performed during the supplemental field investigation: infiltrometer tests and single-well pumping tests. These tests will provide data to meet the following objectives:

- Provide estimates of horizontal hydraulic conductivity in the waste viscose of the basins
- Improve estimates of horizontal hydraulic conductivity in the overburden adjacent to viscose basins 9, 10, and 11
- Characterize hydrologic parameters for use in estimating recharge rates to the viscose basins.

2.4 Data Quality

Data quality objectives (DQOs) are qualitative and quantitative statements, established prior to data collection, that specify the quality of data required to support project-specific activities. General DQOs for the supplemental field investigation sampling activities are summarized in Sections 2.1 through 2.3, above. These sampling objectives identify the type and quantity of data to be collected, the conditions under which the data will be collected, and the intended end uses of the data. The data generated during this supplemental field investigation, along with historical data, will be used to determine the extent of contamination as well as make remedial decisions. As required by the site-wide QAPP (ERM 1999), critical data quality indicators (DQIs) were developed for the supplemental field investigation. These quantitative DQIs are summarized in Section 7.2 and in Tables A-8 through A-15 for this phase of the investigation.

Five analytical levels, identified as Target Analytical Options I through V (ERM 1999) have been identified in previous FSAPs for site activities. These Target Analytical Options are identified as:

- Target Analytical Option I – Field screening using screening kits or portable field instruments. Results are often not compound specific or quantitative.
- Target Analytical Option II – Field screening using more sophisticated portable instruments, including mobile onsite laboratories.

- Target Analytical Option III – Analyses performed in an offsite analytical laboratory that may or may not use Contract Laboratory Program (CLP) analytical procedures. Complete documentation packages are not generated by the laboratory for Option III.
- Target Analytical Option IV – Routine analytical services where all analyses are performed in offsite analytical laboratory following SW846 analytical protocols. Complete documentation packages as specified in the CLP Statements of Work (SOWs) are generated by the analytical laboratory for Option IV. The data packages will include the items specified in Appendix A of the U.S. EPA Region III Superfund Data Validation Policy.
- Target Analytical Option V – Analyses by non-standard methods that are performed by offsite analytical laboratories where method development or method modification may be required for specific constituents or detection limits.

The Target Analytical Options for the analyses conducted for the supplemental field investigation are included in Tables A-8 and A-9 for the analyses that will be conducted in offsite laboratories. Field parameters (temperature, pH, specific conductance, turbidity, Eh, dissolved oxygen, and iron speciation) collected using field portable instruments will be considered Target Analytical Option II.

As required by the QAPP, the analytical results generated during the supplemental field investigation will be subject to data validation and assessment. The four data validation levels identified in the QAPP are as follows:

- Level 1 consists of 100-percent validation and assessment and includes review, cross-checking, and recalculation of all values, and qualification of results that do not meet the DQIs.
- Level 2 consists of reviewing all reporting forms, calibrations, and QC results. The raw data are included in the laboratory data package to allow the data validator to recalculate at least one sample for each method of analysis (i.e., metals by ICP, arsenic by GFAA, etc.). Qualifiers are applied to the data by the validator for results that do not meet the DQIs.
- Level 3 consists of reviewing all summary forms but does not include a review of the raw data. Qualifiers are applied to the data by the validator for results that do not meet DQIs.
- Level 4 consists of reviewing the data summary forms for the samples and the blanks. Qualifiers are applied to the data by the validator for selected results that do not meet DQIs.

The data validation level for each of the analyses is listed in Tables A-8 and A-9. The field parameter data will not be subject to validation. The analytical laboratories that generate the data will be required to submit data packages that are sufficient to conduct the designated level of validation (i.e., complete data packages with raw data for Level 2; validation and summary forms only for Level 4). The data generated for the project will be compared to the task-specific DQIs to assess the usability of the reported data.

3. Groundwater Monitoring Well and Temporary Wellpoint Installation

This section addresses the specific procedures for drilling, installing, and developing viscose basin and overburden temporary wellpoints, Geoprobe® temporary wellpoints, overburden monitoring wells, and bedrock monitoring wells, as outlined in the FS work plan. All wells/temporary wellpoints will be constructed by a drilling company that holds a registered contractor's license in the State of Virginia.

3.1 Monitoring Well and Wellpoint Locations

A total of 8, and possibly 9, new groundwater-monitoring wells are proposed to address data gaps in the existing site groundwater database. The locations of the proposed monitoring wells are indicated in Figure A-1. Two overburden wells, five shallow bedrock wells, and one intermediate bedrock well are proposed for Phase I of the field investigation. A ninth monitoring well (343) may also be completed in the deep bedrock aquifer zone, depending on the review of analytical data for offsite wells located west of the Shenandoah River (as described in Section 6.2.1.4 of the FS Work Plan). These wells will be sampled during the supplemental groundwater investigation (Section 4), and a decision regarding installation of well 343, and the construction of this well, will be made in conjunction with U.S. EPA. Installation of well 343, if necessary, will be executed during Phase II of the field investigation.

Fourteen Geoprobe® temporary wellpoints are proposed for installation in the overburden downgradient of the plant area during Phase I of the field investigation. The proposed locations for the Geoprobe® temporary wellpoints are shown in Figure A-1. These locations may be adjusted in the field based on site conditions and the need to accommodate limitations of field installation equipment and/or underground utility locations. In the event that the locations of any temporary wellpoints are adjusted, the actual locations will be recorded on a copy of Figure A-1 to aid sampling personnel during subsequent sampling and water-level monitoring efforts.

A total of 14 temporary wellpoints are proposed for installation at the Avtex site during Phase II of the field investigation using hollow-stem auger drilling techniques. Of these 14 temporary wellpoints, nine will be installed in viscose basins 9, 10, and 11 (three per basin), and five will be installed in the overburden adjacent to the basins. The approximate locations of these temporary wellpoints are indicated in Figure A-2. These locations may be adjusted in the field based on site conditions and the need to accommodate limitations of field installation equipment. In the event that the locations of any temporary wellpoints are adjusted, the actual locations will be recorded on a copy of Figure A-2 to aid sampling personnel during subsequent sampling and water-level monitoring efforts.

3.2 Subsurface Utilities Identification

Before drilling begins, an underground utility check will be performed by reviewing available utility maps and plant photos, and through discussions with the FMC manager of site remedial activities. Public utilities will be located by the utility agencies. A private utility-locating company may also be used, if necessary.

3.3 Equipment Decontamination

Prior to drilling the boreholes for monitoring well or temporary wellpoint installation, all drilling tools (e.g., augers, steel casing, and drill equipment) and well completion materials will be decontaminated using a hot-water pressure washer. Other equipment (e.g., water-level indicators) will be washed in a solution of Liquinox, rinsed with water, and rinsed with deionized water before being placed in a borehole or well. Waste materials (e.g., water and cuttings) will be contained and disposed of as described below in Section 7.6.

3.4 Monitoring Well and Wellpoint Installation

This section describes the procedures that will be followed during the installation of monitoring wells

3.4.1 Geoprobe® Temporary Wellpoints

Boreholes will be created at each of approximately 14 locations in the overburden along the western boundary of the plant area using a Geoprobe® rig. The boreholes will be advanced to the overburden/bedrock contact. No soil sampling or logging will be included in this scope of work. PID measurements of material being removed from the boreholes will be taken and recorded in the field logbook. Groundwater samples will be collected from the overburden by advancing a Geoprobe® borehole to the appropriate depth, pulling the probe rods, and installing a prepacked Geoprobe® well screen. The well screen will be placed immediately above the bedrock/overburden interface such that the temporary wellpoint will be screened over the lower 5 ft of the overburden. One groundwater sample will be collected from each borehole. Figure A-3 presents a schematic of a Geoprobe® temporary wellpoint. Soil cores produced during the Geoprobe® wellpoint installation will be screened for organics using a photoionization detector (PID).

On completion of each Geoprobe® borehole, the temporary wellpoint will remain in place for surveying (Section 3.6) and site-wide water-level measurements (Section 5). Water-level measurements will be made after water levels in the temporary well points have been allowed to return to static levels. After the water-level measurements have been

made, the temporary wellpoint will be removed, and the borehole will be backfilled with a dry bentonite seal (granules) and hydrated with water or, alternatively, with a bentonite grout mixed to the manufacturer's recommendations. The driller will calculate the borehole volume to ensure that the proper volume of grout is placed in the annulus. The subcontractor will obtain permission from Exponent prior to selection and purchase of seal materials.

3.4.2 Viscose Basin Temporary Wellpoints

Two to three boreholes will be advanced at each of the three locations indicated in Figure A-2 for each of viscose basins 9, 10, and 11 (a total of nine locations) to collect waste viscose samples and to install temporary wellpoints. The initial borehole at each location will be advanced using hollow-stem auger drilling methods to the bedrock beneath the waste viscose in each basin (up to approximately 25 ft total depth below ground surface). Samples of waste viscose from the initial borehole at each location (i.e., the borehole used for installation of the temporary wellpoint) will be collected continuously over the total depth of each borehole using a 2-in.-diameter stainless steel split-spoon sampler for visual description and for collection of a composite sample for laboratory testing. The second and third boreholes will be installed using hollow-stem auger drilling methods at a distance approximately 10 ft away from the temporary wellpoint borehole, to collect waste viscose samples at specific depth intervals for testing of hydrologic parameters, consolidation, shear strength, electrical resistivity, and chemical characterization as described in the FS work plan and in Section 4.2. These boreholes will be backfilled, as necessary, with bentonite following completion of the sample collection activities.

The boreholes will be advanced using an ATV-mounted, track-mounted, or skid-mounted hollow-stem auger drilling machine. The existing fly-ash roads on the viscose basins will be used, to the extent possible, to access the wellpoint and borehole locations. Plywood, Marshall Matting®, or other suitable surface stabilization methods may be used, as necessary, to facilitate access to the borehole locations. The initial boreholes will be advanced to the bedrock beneath the waste viscose in each basin (up to approximately 25 ft total depth below ground surface [bgs]). The second and third boreholes will be advanced to the depth necessary to achieve the sampling objectives.

Temporary wellpoints will be installed in the initial viscose basin boreholes at each of the nine locations to collect samples of pore water for laboratory analysis, measure water levels, and conduct single-well pumping tests, which will be used to estimate the hydraulic conductivity of the waste viscose material. Before installing temporary wellpoints, any portion of a borehole that extends below the base of the viscose basin into overburden and/or bedrock will be backfilled with bentonite. A minimum of 1 ft of sand will be placed on top of the bentonite to prevent migration of bentonite into the temporary wellpoint screen interval.

Temporary wellpoints will be installed inside the hollow-stem augers following completion of the boreholes described above. The temporary wellpoints will be

constructed of 2-in. Schedule 40 PVC casing with threaded couplings. A 10-ft section of 0.010-in. mill-slotted PVC well screen with an end plug will be placed at the bottom of the temporary wellpoint at the base of the waste viscose. Blank PVC casing will extend from the top of the screen to the ground surface. Stainless-steel centralizers will be attached at the top and bottom of the well screen.

The annular space will be backfilled with No. 10–20 Colorado silica sand or equivalent to approximately 1 ft above the top of the screen. To prevent caving, all annular fill materials will be added to the borehole while the augers are slowly being removed.

A 2- to 3-ft-thick bentonite seal will be placed on top of the sand pack. The bentonite seal will be hydrated with clean water and allowed to set for sufficient time to ensure a proper seal. High-solids bentonite grout or bentonite chips will be placed from the bentonite seal to within 2 ft of the ground surface. The driller will calculate the volume of the annular space to ensure that the proper volume of grout is placed in the annulus. The temporary surface completion will consist of an aboveground protective casing and locking cap. Typical construction details are shown on Figure A-4.

3.4.3 Overburden Temporary Wellpoints

Temporary wellpoints will also be installed in overburden at five locations in the vicinity of viscose basins 9, 10, and 11 (Figure A-2). The purpose of these temporary wellpoints is to measure water levels in the overburden adjacent to the viscose basins and to conduct single-well pumping tests to provide additional estimates of horizontal hydraulic conductivity in the overburden. The boreholes will be advanced using hollow-stem auger drilling methods to the overburden/bedrock contact. Boreholes will be advanced and temporary wellpoints installed in a manner similar to that described above for the viscose basin temporary wellpoints. The overburden temporary wellpoints will be screened over the lower 10 ft of the overburden (Table A-1a). Surface completion may be modified from the viscose basin temporary wellpoints completion by constructing either an aboveground monument with steel protective riser or a flush-mounted watertight monument. Typical construction details are shown on Figure A-4.

3.4.4 Overburden Monitoring Well

Two monitoring wells will be installed in the overburden at the approximate location indicated in Figure A-1 to assess background overburden groundwater quality. A borehole will be drilled using hollow-stem auger and/or air rotary methods to the overburden/bedrock contact at an approximate depth of 20–25 ft bgs (Table A-1b).

Soil samples will be collected from the borehole with a split-spoon sampler at a minimum of 5-ft intervals for lithologic characterization. The sampler will be driven 18 in. by a 140-lb weight falling a vertical distance of approximately 30 in. (i.e., standard penetration test [SPT]). The number of vertical drops (blow counts) needed to advance the sampler each 6-in. increment will be indicated on the borehole log.

The overburden groundwater monitoring wells will be constructed of 2-in. Schedule-40 PVC casing with flush-threaded couplings. A 10-ft section of 0.010-in. mill-slotted PVC well screen with an end plug will be placed at the bottom of each well, with the upper 3–4 ft of the screen interval above the vadose-zone/groundwater interface. Blank PVC casing will extend from the top of the screen to the ground surface. Stainless-steel centralizers will be attached at the top and bottom of the well screen.

The annular space will be backfilled with No. 10–20 Colorado silica sand or equivalent to approximately 1 ft above the top of the screen. To prevent caving, all annular fill materials will be added to the borehole while the augers are being slowly removed.

A 2- to 3-ft-thick bentonite seal will be placed on top of the sand pack. The bentonite seal will be hydrated with clean water and allowed to set for sufficient time to ensure a proper seal. High-solids bentonite grout or bentonite chips will be placed from the bentonite seal to within 2 ft of ground surface. The driller will calculate the volume of the annular space to ensure that the proper volume of grout is placed in the annulus. The surface completion will consist of either an aboveground monument with steel protective riser or a flush-mount watertight monument. Typical construction details are shown in Figure A-4.

3.4.5 Bedrock Monitoring Wells

This section addresses the specific procedures for drilling, installing, and developing six bedrock groundwater monitoring wells at the Avtex site. Five of the wells (at locations 128, 129, 130, 131, and 132, Figure A-1) will be completed in a water-bearing zone within the shallow depth zone of the bedrock aquifer, to monitor the interval between 35 and 45 ft bgs, with a total well depth of 45 ft bgs, as indicated in Table A-1b. The sixth bedrock well (at location 232, Figure A-1) will be completed within the intermediate depth zone of the bedrock aquifer, to monitor the interval between 120 and 140 ft bgs, as indicated in Table A-1b. In addition to the five shallow bedrock wells and one intermediate bedrock well, a deep bedrock well (well 343) may be installed to an approximate depth of 330 ft at a location southwest of the site during Phase II of the field investigation (Figure A-1). As described in Section 6 of the FS Work Plan, installation of this well is contingent on the results of groundwater sampling in offsite wells located west of the Shenandoah River (wells 115, 136, 137, 162, 177, 181, 185, 215, GM2A, GM2B, and 315). Installation of this well may require additional procedures such as construction of a rough access road and a concrete drilling pad. If this well is determined to be necessary, an addendum to this FSAP, describing additions and modifications to these bedrock well installation procedures that will be required for well 343, will be prepared and submitted to EPA.

Bedrock well installation will include setting the surface casing in the overburden, and advancing the borehole to the target depth using air rotary or hollow-stem auger methods, with casing advance, Tubex[®], or other equivalent methods; and installation of a 2-in.-diameter PVC monitoring well, screened over the depth interval to be monitored. The

length of the interval to be monitored in the shallow bedrock is 10 ft, and in the intermediate bedrock is 20 ft. Groundwater grab samples will be collected periodically as the borehole advances, to assess the potential presence of site chemicals. Field measurements of specific conductance and pH may provide indications of site chemicals in groundwater.¹ The groundwater grab samples will be extracted from the well during the air-rotary drilling process. Specific conductance and temperature will be measured using the appropriate meter, which will be calibrated daily (per Standard Operating Procedure [SOP] 56) and operated in accordance with the manufacturer's instructions, with data to be recorded in the field logbook.

3.4.5.1 Installation of Surface Casing

Surface casing will be set and grouted in place before the borehole is drilled into the bedrock. The purpose of the surface casing is to seal off the well from any potential contaminants from the surface, as well as to seal off groundwater in the overburden from the bedrock. Surface casing will be installed as follows:

Steel surface casing will be advanced through the unconsolidated overburden material and driven approximately 1–4 ft into the competent bedrock. Final selection of initial casing size will be made in consultation with the lead hydrogeologist and a qualified drilling contractor. The cuttings will be removed from the casing, and a bentonite seal (minimum of 2 ft thick) will be placed in the bottom of the borehole. The bentonite seal will be hydrated and allowed to set a minimum of 1 hour before drilling operations continue.

3.4.5.2 Bedrock Monitoring Well Construction

A schematic for the bedrock well design is presented in Figure A-5; it is constructed as follows:

- After surface casing is set through the overburden and the bentonite seal is hydrated, the borehole will be advanced into bedrock by the air rotary drilling method. Steel casing will be advanced as the borehole progresses (using an under-reamer or casing shoe). If the Tubex[®] system is used, the pilot bit and eccentric reamer creates a hole sufficiently large for a casing tube to slide down behind the reamer. Flush-jointed casing is then advanced through the under-reamed borehole. Either of these methods will provide a better evaluation of groundwater flow and subsurface lithology than conventional air-rotary methods without casing advance.

¹ Groundwater within the dense carbon disulfide plume typically had a specific conductivity of >5,000 $\mu\text{S}/\text{cm}$ and pH of >9 during the 1994 sampling event.

- After the water-bearing target zone in the bedrock aquifer has been reached, temporary casing will be installed to the bottom of the borehole. The drill string will be removed, and the monitoring well will be constructed inside the temporary casing as specified below. The temporary casing will be removed following well installation.

The groundwater monitoring wells will be installed inside the temporary casing, in accordance with all applicable laws, regulations, and guidelines. The groundwater monitoring wells will be constructed of 2-in. Schedule 40 PVC casing with threaded couplings. All wells deeper than 100 ft will be constructed using Schedule 80 PVC casing. A 20-ft section of 0.010-in. mill-slotted PVC well screen with a threaded end cap will be placed at the bottom of the well. Blank PVC casing will extend from the top of the screen to above the ground surface. Stainless-steel centralizers will be attached at the top and bottom of the well screen. The annulus between the well and temporary casing will be backfilled with No. 10–20 Colorado silica sand or equivalent to approximately 1–2 ft above the top of the screen. All annular fill materials will be added to the borehole via a tremie pipe as the temporary casings are removed.

A 2- to 3-ft-thick bentonite seal will be placed on top of the sand pack. The bentonite seal will consist of bentonite chips or pellets specifically designed to be emplaced in the saturated zone. The bentonite seal will be hydrated with formation water or by the addition of clean water and allowed to set for sufficient time to ensure a proper seal. High-solids bentonite grout will be placed with a tremie pipe from the bentonite seal to within 2 ft of the ground surface. The driller will calculate the volume of the annular space to ensure that the proper volume of grout is placed in the annulus. A concrete surface seal approximately 1–2 ft thick will be placed on top of the bentonite grout to the surface level. The surface completion will consist of an aboveground monument with protective steel casing that extends at least 2 ft above grade and has a lockable cap. The protective steel casing will extend at least 3 ft below the surface and will be at least 2 in. above the PVC casing.

Figure A-5 illustrates the design of bedrock monitoring wells with stickup protective casing. If a flush-mount protective wellhead is necessary, the stickup protective casing shown in Figure A-5 will be replaced with a heavy duty metal valve box or locking vault with a watertight seal installed at grade.

3.5 Temporary Wellpoint and Monitoring Well Development

Following temporary wellpoint (both the Geoprobe® and viscose basin wellpoints) and monitoring-well construction and a minimum 24-hour bentonite/grout stabilization period, each temporary wellpoint or monitoring well will be developed to remove fine-grained materials from within and around the sand pack. Development will be achieved by pumping and surging with a non-dedicated positive-displacement pump, stainless steel or PVC bailer, surge block, centrifugal or positive-displacement bladder pump, or combination of these technologies. The temporary wellpoint or well will be alternately

surged and overpumped until the discharge water is clear of fine materials (fines) or a minimum of 10 casing volumes have been removed. Water quality parameters (pH, temperature, and specific conductance) will be monitored periodically during development. Water quality meters will be calibrated daily in accordance with manufacturer's specifications (SOP 56). Following well development, a two-week stabilization period will be allowed prior to conducting any groundwater sampling.

3.6 Survey

Following installation, a professional land surveyor will survey the locations of the new wells, the Geoprobe® temporary wellpoints, and the viscose basin and overburden temporary wellpoints to a horizontal accuracy of 1.0 ft. The reference elevation will be determined to an accuracy of 0.01 ft. The location will be referenced to the appropriate state plane coordinate system and U.S. Geological Survey (USGS) datum.

3.7 Borehole and Well Data Reporting

Field activities will be documented in the field logbook and logged on field data sheets as appropriate in general accordance with methods described in the QAPP (ERM 1999). Field forms that will be used to document borehole lithology and well completion details are provided in Attachment A-2.

A lithologic log will be prepared for each borehole. The borehole log will include information on soil types, rock types, color, texture, odors, water levels, drilling conditions, and any other pertinent information. Soils will be classified in accordance with the Unified Soil Classification System, as described in ASTM method D 2488-93 (Attachment A-3). Rock types will be classified using standard geological nomenclature. Solid samples will not be collected during the installation of the Geoprobe® temporary wellpoints, and therefore, a lithologic log will not be prepared for these wellpoints.

3.8 Management of Investigation-Derived Wastes

Investigation-derived wastes generated at the Avtex site (e.g., drilling water, decontamination water, development water, and drill cuttings) will be managed according to the procedures described in Section 7.6.

4. Aqueous and Solid Media Sampling

This section describes the locations of and procedures for collection of samples of groundwater, viscose basin pore water, and viscose basin solids during the supplemental field investigation.

In addition to the data produced by the work described herein, the FS will also incorporate data from other site activities. Specifically, in support of the FS for OU-10 at the Avtex site, seven overburden monitoring wells, seven shallow bedrock monitoring wells, and two intermediate bedrock monitoring wells will be sampled during the Phase I investigation. The samples will be analyzed for TCL VOCs and SVOCs, TAL metals, and ammonia nitrogen. These data will also be used in the evaluation of OU-7.

4.1 Groundwater and Pore-Water Sampling Procedures

Groundwater/pore-water samples will be collected from selected wells and temporary wellpoints to characterize site water quality and to provide samples for use in laboratory testing. The following sections identify the locations of the wells/wellpoints to be sampled and summarize the sampling procedures. The required equipment for this sampling effort is listed in Attachment A-4.

4.1.1 Sampling Locations

A total of 75 groundwater-monitoring wells (8 proposed and 67 existing)², 14 Geoprobe[®] temporary wellpoints, and nine viscose basin temporary wellpoints (temporary wellpoints WP01–WP09) will be sampled to characterize the current groundwater and viscose basin pore-water quality at the Avtex site. The locations of the monitoring wells and the temporary wellpoints are indicated in Figures A-6a through A-6d and A-2, respectively.

In addition, seven replicate groundwater or pore-water samples will be collected for use in laboratory testing of carbon disulfide hydrolysis at each of the following monitoring wells/temporary wellpoints: 116, 205, 216, 316, WP01, WP04, and WP07. Each replicate sample will consist of three VOA vials. In addition, five 500-mL septum-sealed amber glass bottles will be filled at each of the wells/wellpoints. Three of the replicate samples and three of the 500-mL glass bottles from each well will be spiked with 0.2, 2.0, and 4.0 mL of 30 percent hydrogen peroxide. Preservative will not be used for the remaining samples. The locations of the monitoring wells and temporary wellpoints are shown in Figures A-6a through A-6d and A-2, respectively.

² Because installation of well 343 is contingent on the Phase I sampling results, it was not included in the count of proposed wells.

Samples of viscose basin pore water from temporary wellpoints WP01, WP04, and WP07 will be collected for use in laboratory testing of static electrical conductivity. The locations of these temporary wellpoints are shown in Figure A-2.

4.1.2 Sample Collection Procedures

This section presents procedures that will be used to measure water levels and to purge and sample monitoring wells and temporary wellpoints.

4.1.2.1 Static Water-Level Measurements

Static water-level measurements will be performed immediately prior to purging/sampling individual monitoring wells and temporary wellpoints. Water levels will be measured using an electronic water-level instrument following procedures in SOP 19 (Attachment A-5). Water-level measurements will be recorded on a groundwater field data form (see Attachment A-6) to the nearest 0.01 ft. A complete survey of site water levels will be performed after the completion of groundwater sampling and field activities, as described in Section 5.

4.1.2.2 Groundwater Well/Temporary Wellpoint Sampling

This section summarizes the procedures that will be used to purge and sample groundwater monitoring wells and temporary wellpoints at the Avtex site. Prior to purging, a groundwater-level measurement will be taken and recorded on the groundwater sampling field data form. After measuring the groundwater level, and prior to sampling, each monitoring well/temporary wellpoint will be purged. The purging technique and the type of equipment used to purge each well will differ based on well type, well yield, well diameter, the depth to water, and the amount of pump submergence possible. Due to the complexity of the purging process, decision trees and supporting tables have been provided in Attachment A-7 to assist field personnel in selecting the appropriate purging protocols at each well/wellpoint.

The low-flow purging and sampling techniques described in U.S. EPA Region III Technical Bulletin Number QAD023 (Attachment A-8; U.S. EPA 1999), will be used, to the extent possible, for the overburden wells and the viscose basin wellpoints. These techniques are not appropriate for open-borehole wells, wells of large diameter, or wells with large intervals to be monitored (U.S. EPA 1999). Most of the bedrock wells at the site are 4- or 6-inch diameter open boreholes, and many have large open intervals. Pumping rates, however, will be minimized to the extent reasonably possible when purging and sampling the bedrock wells and Geoprobe® wellpoints, to minimize drawdown. To the extent possible, the water level in the wells will not be allowed to fall below the top of the screened interval or the open borehole in the bedrock wells.

Because groundwater has not been sampled at the site for six years, it is possible that some of the existing wells will require re-development prior to purging and sampling. Re-development of these wells will be accomplished according to the procedures outlined in Section 3.5. All purge and development water will be contained and transported to the the digester that contains the viscose leachate, as described in Section 7.6. Decontamination procedures for purging pumps and bailers are described in Section 7.5.

Overburden Well, Viscose Basin Wellpoint, and Geoprobe® Wellpoint Purging and Sampling — The overburden wells, viscose basin wellpoints, and Geoprobe® wellpoints that will be sampled at the Avtex site will be purged according to the protocols provided in Attachment A-7. If sufficient submergence is possible (i.e., >5 ft), the wells/wellpoints will be purged and sampled using a Teflon®-lined bladder pump equipped with new ½-inch, Teflon®-lined tubing. The pump will be lowered slowly to the center of the saturated screen section of the well/wellpoint. Once the pump is in place, the water level in the well/wellpoint will be measured and the pump will be started at the lowest flow possible (e.g., approximately 100 mL/min).³ If the water column in the well does not provide sufficient submergence to permit the use of a bladder pump, a peristaltic pump with new ¼-inch, Teflon®-lined tubing, and new medical-grade silicon tubing (used for the pump head) will be used for purging. A peristaltic pump will also be used for purging all of the Geoprobe® wellpoints, because these wells do not have sufficient diameter to accommodate the bladder pump. Before purging, the intake tubing will be lowered slowly into the water column to minimize agitation and loss of VOCs, to a depth of 1 ft below the water level.

The water level in the well will be measured continuously during purging to ensure that drawdown in the well/wellpoint does not exceed 0.2 ft—the maximum drawdown specified by QAD023 (Attachment A-8; U.S. EPA 1999). The pumping rate may be increased, provided that drawdown of the water level remains less than 0.2 ft. Purging will continue until field parameters are stable, as described below. In the event that drawdown in the well/wellpoint cannot be stabilized at less than 0.2 ft while purging at the lowest pump setting, the water level will be allowed to lower to a maximum depth of 90 percent of the initial saturated screen interval at the start of purging (i.e., 10 percent of the initially saturated screen interval is dewatered).⁴ If the water level stabilizes at or above this depth, the well will be purged (with the option of increasing the pumping rate if it does not cause the water level to drop below 90 percent of the initial saturated monitoring interval) until the field parameters are stable, and then the well will be

³ Note: Technical bulletin QAD023 recommends that the pump be placed in the well 12 to 48 hours prior to purging/sampling. However, this action is impractical at the Avtex site, given the number of wells being sampled. As a result, care will be taken to lower the pump into the well as slowly as possible immediately prior to purging, in an effort to minimize disturbance of the water column.

⁴ This value was selected as a reasonable limit to minimize cascading effects and potential loss of VOCs.

sampled as described below. If the water level cannot be stabilized at or above this depth, the recharge rate for the well and the volume of water remaining in the well (Volume₁) will be calculated. If three Volume₁ can be purged at the calculated recharge rate in three hours, then the pumping rate will be adjusted to do so, and sampling will be conducted once three Volume₁ are purged and field parameters are stable. If three Volume₁ cannot be purged, then an evaluation will be made as to whether one Volume₁ can be purged in three hours. If one Volume₁ can be purged, then this will be done, and sampling will be conducted after field parameters have stabilized. If one Volume₁ cannot be purged, then as much water as possible will be purged from the well, and the well will be sampled within 24 hours.

Field parameters will be measured by directing the pump outflow through a flow-through cell equipped with probes for measuring pH, specific conductance, Eh, dissolved oxygen, temperature, and turbidity (following the methods for assembly of the flow-through cell and calibration of field instruments described in SOP-56 and SOP-424). To monitor turbidity, a T-valve will be placed in line on the purge tubing in front of the flow-through cell. This valve will allow for filling of the turbidity meter cuvettes at the same time that the other field parameters are measured. The field parameters will be monitored and logged on the groundwater field data form approximately every 5 minutes during purging. Purging will continue until the parameters are all stable. The criteria for determining stabilization will be three successive readings are within ± 0.1 units for pH, ± 3 percent for specific conductance and temperature, ± 10 mV for Eh, and ± 10 percent for turbidity and dissolved oxygen. However, if the turbidity drops below 5 NTUs (i.e., does not stabilize above 5 NTUs), then the turbidity criterion will become obtaining three successive measurements with a turbidity less than 5 NTUs. These turbidity measurements will be at least 5 minutes apart. In the event that turbidity starts at less than 5 NTUs, the turbidity criterion will be that a consistent downward trend in turbidity is not observed—that is, an increase in turbidity needs to be observed in one reading. After parameter stabilization, all six field parameters will be recorded in the data section of the groundwater sampling field data form, and a plastic beaker will be filled from the T-valve for determination of iron speciation per SOP-61.

Upon completion of the iron speciation measurement, the discharge tubing will be cut upflow of the in-line T-valve, and the discharge from the tubing will be collected for laboratory analyses. Care shall be taken to ensure that the discharge tubing does not come in contact with the ground or equipment after it is cut. Groundwater samples will be collected in general accordance with ASTM Standard 4448-85a (1992) (Attachment A-3). Table A-3 and Figure A-6a summarize the parameters to be evaluated in each well/temporary wellpoint to characterize site groundwater/pore-water quality. Sample containers and preservatives for specific parameters and laboratory tests are indicated in Table A-4. At each well/temporary wellpoint, the necessary sample containers will be filled in the order presented in Table A-5.

All sample bottles will be filled directly from the pump discharge tubing. The discharge tubing will not be allowed to contact any of the sample bottles during filling, to minimize potential cross-contamination. VOA vials will be filled to overflowing, capped, and then

inverted and tapped to ensure that no air bubbles are present. If an air bubble is observed, the process will be repeated with a new bottle until no air bubbles are evident. Past sampling experience at the site suggests that turbidity of the groundwater in the overburden wells may be high. As a result, filtered samples will be collected from the overburden wells for TAL inorganics analysis after all of the other sample bottles have been filled. A filtered sample for TAL inorganics will not be collected from the Geoprobe® wellpoints, because these samples are for screening-level purposes. To collect the filtered TAL inorganics sample, unfiltered groundwater will be collected in a clean, unpreserved 1-L HDPE sample bottle. Once sampling is completed at the well, the water in the 1-L HDPE bottle will be passed through a 0.45- μ m, high-volume, in-line groundwater filter using a peristaltic pump and new Teflon®-lined tubing. Approximately 200 mL of the water will be pumped to rinse the filter prior to sample collection, and then a pre-preserved sample bottle for metals analysis will be filled directly from the filter discharge port. In the case of wells/wellpoints being sampled with a peristaltic pump, once all but the VOA vials for VOC analysis have been filled, the pump intake tubing will be removed slowly from the wellpoint, and a disposable, bottom-discharge Teflon® bailer will be lowered slowly into the wellpoint for collection of the VOC sample. The bailer will then be raised out of the wellpoint, and a low-flow discharge tube will be attached to fill the VOA vials used for VOC sample collection. This process will continue until each VOA vial is filled, with no air bubbles present.

Bedrock Well Purging and Sampling — A low-flow, submersible centrifugal pump with new ½-inch Teflon®-lined tubing will be used to purge and sample the bedrock wells. Shallow, intermediate, and deep bedrock wells each require different purging procedures; Attachment A-7 provides detailed methods that will be used for purging each type of bedrock well. Before purging, the submersible pump will be lowered slowly into the water column to minimize agitation and loss of VOCs, to the midpoint of the saturated open-borehole interval. The pump will be started at the three-hour purge rate (see Table 1 of Attachment A-7), and water levels will be monitored continuously. At this point, the prescribed purging procedures for shallow, intermediate, and deep bedrock wells are all unique, and Attachment A-7 must be consulted to establish the correct purging procedure, based on bedrock well depth.

The methods for measuring the field parameters, evaluating parameter stabilization, and collecting groundwater samples are the same as those described in the above section (*Overburden Well, Viscose Basin Wellpoint, and Geoprobe® Purging and Sampling*). A filtered sample will not be collected from the bedrock wells, because these wells do not have a history of containing groundwater with high turbidity. Table A-3 and Figures A-6b through A-6d summarize the parameters to be evaluated in each well to characterize site groundwater quality. Sample containers and preservatives for specific parameters and laboratory tests are indicated in Table A-4. At each well, the necessary sample containers will be filled in the order presented in Table A-5.

4.1.2.3 Field Quality Control Samples

Quality control samples to be incorporated into the sampling program include trip blanks, field blanks, equipment rinsate blanks (both unfiltered and filtered, as necessary), and field duplicates. A trip blank for VOCs will be included in every cooler containing VOC samples that is sent to the analytical laboratory. Field duplicates will be collected at a frequency of 1 each per 20 site samples and analyzed for all analytes at the Target Analytical Option used for the native samples of that type. Field blanks and equipment rinsate blanks will be collected and submitted at a rate of 1 each per 20 site samples or 1 each per week—whichever is more frequent. However, these quality control samples will be analyzed only for the TCL VOCs, TCL SVOCs, TAL inorganics, PCBs, organochlorine pesticides, or analytes that must meet Target Analytical Option IV data quality objectives. The analytes TDS, alkalinity, chloride, silica, and sulfate need to meet Target Analytical Option III data quality objectives, and will serve only as indicators of overall water quality. However, these analytes will also be included in the analyses performed on the field blanks and equipment rinsate blanks.

4.1.2.4 Laboratory Quality Control Samples

During sample collection activities, field staff will collect the appropriate volume, so that the analytical laboratory can perform the matrix spike/matrix spike duplicate analysis at a 1:20 frequency, as specified in the QAPP (ERM 1999).

4.2 Sampling Solid Media in Viscose Basins 9, 10, and 11

Samples of waste viscose and overburden soils will be collected from within/below viscose basins 9, 10, and 11 to characterize the physical and/or chemical properties of these materials. Table A-6 summarizes the viscose basin sampling and analysis program, including sample location, anticipated sample depth, sample identification number, sample matrix, analyses to be performed, and the laboratory that will perform the analyses. Samples will be submitted to Lancaster Laboratories, Inc. (LLI), GeoSyntec Consultants (GSC), Applied Hydrology Associates, Inc. (AHA), or SmartWorm, Inc. (SWI) for the appropriate analyses. Addresses for these laboratories are provided in Table A-7. This sampling effort will be coordinated with the temporary wellpoint installation described in Section 3.6. The required equipment for this sampling effort is listed in Attachment A-4.

4.2.1 Sampling Locations

Samples of waste viscose and/or overburden will be collected from three locations in each of viscose basins 9, 10, and 11 (Figure A-2). At each of these locations, an initial borehole will be advanced into the waste viscose to install the temporary wellpoint, to collect samples of waste viscose for visual description, and to collect a depth-integrated composite sample of waste viscose for laboratory testing. At two or three locations in

each basin, a second borehole will be installed approximately 10 ft away from the borehole installed for the temporary wellpoint, to collect samples for physical and chemical analyses and for use in laboratory testing. A third borehole will be installed at one of these locations to collect samples for consolidation and shear testing.

4.2.2 Sample Collection Procedures

Sampling of viscose basin and overburden material will be coordinated with the previously described temporary wellpoint installation. The drilling methods that will be used during the viscose basin sampling are described in Section 3.5. The boreholes used to collect all viscose basin samples will be collocated with the temporary wellpoints that are being installed in viscose basins 9, 10, and 11. An initial borehole will be advanced at each location to the bedrock beneath the waste viscose in each basin (up to approximately 25 ft total depth below ground surface) using hollow-stem auger drilling methods. Samples of waste viscose from the initial borehole at each location (i.e., the borehole used for installation of the temporary wellpoint) will be collected continuously over the total depth of each borehole using a 2-in.-diameter stainless steel split-spoon sampler. A visual description of the color, texture, and consistency of the waste viscose, as well as any other relevant parameters, will be recorded on a borehole log for the entire sample length. The waste viscose from throughout the borehole (excluding the crust layer and any overburden) will be combined in a 3.5-gallon high-density polyethylene (HDPE) bucket to create a single composite for each of the three temporary wellpoint locations in each viscose basin. Pore water from the corresponding temporary wellpoint will be pumped into the bucket to eliminate the headspace.

A second borehole will be installed at two selected viscose basin temporary wellpoint installation locations per basin, and a third borehole at one selected location per basin will be installed using hollow-stem auger drilling methods at a distance approximately 10 ft away from the temporary wellpoint borehole, to collect waste viscose samples at specific depth intervals. Specific sample depths and laboratory testing and analyses are summarized in Table A-6. Specific-depth-interval samples from the second borehole at two selected locations will be collected using a 2-in.-diameter split-spoon sampler. The samples will be placed into sample containers and submitted for hydrological characterization, chemical characterization analyses, and direct electrical resistance heating tests. Additionally, in one selected second borehole in each viscose basin, a sample from the top of the overburden material (confirmed to be present on the basis of the temporary wellpoint installation borehole) underlying the basin will be collected and submitted for laboratory analysis of saturated vertical hydraulic conductivity. The third borehole will use a 3-in.-diameter Shelby tube (2 ft long) to collect samples of sufficient size for the consolidation and shear testing (Table A-6). Following sample collection, the second and third boreholes at each location will be backfilled, as necessary, with bentonite.

Upon removal, each split spoon (hydrogeological characterization and direct electrical resistance heating tests) will be opened, and the stainless steel sleeves will be sealed immediately on both ends with caps and Teflon tape. Shelby tube samples will be capped

immediately on both ends and sealed with Teflon tape. The outside of each sample will then be wiped clean with a paper towel and a sample label will be attached to the sleeve. The sleeve will then be wrapped in aluminum foil and placed inside a Ziploc bag. The sample will then be placed on ice in a sample cooler at 4° C. To aid in recording the samples on the chain-of-custody/sample-analysis-request (COC/SAR) form (Attachment A-9), the tag number of each sleeve will be written on the outside of each Ziploc bag.

At depth intervals where samples for chemical characterization are being collected, the stainless steel sleeve will be eliminated. Upon retrieval, the split spoon will be opened and the solid samples for VOCs will be collected as quickly as possible. After the VOC samples are processed, one 16-oz. glass jar will be filled from each split-spoon sampler for analysis of inorganics, conventional parameters, and moisture content. Sampling of VOCs will be performed following the procedures in SW846 Method 5035 using the EnCore™ sample collection device. Samples for both low- and high-level analysis will be collected for each sample (i.e., three 5-g EnCore™ samplers for each sample). At the laboratory, one of the 5-g EnCore™ samplers will be used for high-level VOC analysis, and the remaining two samplers will be used for low-level analysis, if necessary. These analyses will be subject to a 48-hour holding time. A field test will be performed on six samples of viscose waste to assess the effervescence caused by the addition of sodium bisulfate as a preservative (testing conducted during Phase I groundwater sampling, July 2000). Results from this testing will be provided to Lancaster Laboratory to assist them with establishing the appropriate sample-handling procedures.

If sufficient sample material is not recovered from the second or third boreholes, additional sample material will be collected from an additional borehole installed adjacent to the boreholes.

Lithologic logging of any overburden or bedrock materials collected from the boreholes will be performed in accordance with ASTM method D 2488-93 (Attachment A-3).

4.2.3 Field Quality Control Samples

Quality control samples to be collected during sampling of solid media will include one field blank, one equipment rinsate blank, and one field duplicate for chemical characterization analysis to meet the Target Analytical Option IV data quality objectives. The field duplicate sample will be collected by sinking a borehole immediately adjacent to a selected borehole used to collect a chemical characterization sample and removing a sample from the corresponding depth interval. Field quality control samples for material/geotechnical properties and laboratory testing for Target Analytical Option III data quality objectives will not be collected.

4.3 Sample Designation

Sample designation will follow the general format specified in Section 3.3.1.6 of the QAPP (ERM 1999). Each aqueous and solid sample collected in the field will be

assigned a sample number, a unique tag number, and a unique sample identification number (Sample ID). To ensure that the analytical lab is analyzing samples blind, the sample ID will be recorded only in the field logbook and will not be placed on any sample bottle or COC/SAR form sent to the analytical laboratory. The sample ID will be entered into the site database upon receipt of the data from the analytical lab to aid in subsequent data identification and analysis. All samples being sent to the analytical laboratory will be identified with a sticker sample label containing a unique sample number, the site name, the date, the time, the sampler's initials, the sample preservative, and a unique tag number. An example tag is provided in Attachment A-9. A description of the sample number, tag number, and sample ID number is presented in the following sections.

4.3.1 Sample Numbers

The sample number will contain six digits, including a two-digit media code and a four-digit number. For this field investigation, the following media codes will be used for sample numbers:

- **SS** – surface soil
- **BH** – subsurface soil or bedrock from borehole
- **VM** – viscose basin material
- **GW** – groundwater/pore water.

The last four digits of the sample number will start at 0001 and will increase consecutively for each medium (e.g., for groundwater samples: GW0001, GW0002, etc.). Field sampling crews will be assigned sample number blocks, if needed, to avoid using duplicate sample numbers.

4.3.2 Tag Numbers

The tag number is a unique 5-digit number that is pre-printed on the bottom of each sample tag (Attachment A-9). Numbered blocks of sample numbers will be given to sampling crews to ensure that sample blocks have consecutive tag numbers.

4.3.3 Sample ID Numbers

The Sample ID number will be noted in the field logbook for inclusion into the database at a later date. Descriptions of the derivation of the Sample ID number for aqueous and solid media samples are presented below.

4.3.3.1 Groundwater/Pore Water

The sample ID for groundwater and pore-water samples will consist of a combination of the following codes, each separated by a hyphen: a site code, a management unit code, a well series code, a well ID code, and a QC code (for field QC samples only). The following describes each code:

- *Site code* – A two-letter identifier, **AV**, representing the Avtex site.
- *Management unit code* – A two-letter identifier representing groundwater (**GW**) or pore water (**PW**).
- *Well series code* – A two-letter identifier indicating that the sample is from an onsite (**ON**) well, an off-site (**OF**) well, or a temporary wellpoint (**WP**).
- *Well ID code* – A unique, three-digit number will be assigned for the new monitoring wells, where the first digit indicates the well depth zone, and the second and third digits indicate the well location. For example, the four wells in the well nest at location 01 would have the designations of 001 for the overburden well, 101 for the shallow bedrock well, 201 for the intermediate-depth well, and 301 for the deep-bedrock well. Existing wells will retain the same well ID code used in previous studies. For the new temporary wellpoints, the well ID code will be a unique two-digit number that will indicate the temporary wellpoint location.
- *Quality control (QC) code* – A single-letter code indicating that the sample is a VOC water trip blank (**A**), a field blank (**B**), an equipment rinsate blank (**C**), or a field duplicate (**D**). The first three codes (i.e., A, B, or C) will be followed, in parentheses, by the month, day, and year that the sample was collected [e.g., B(08/22/00) for a field blank collected on August 22, 2000]. No hyphen will be used between the well ID code and the “D” QC code.

Examples of Sample ID numbers are as follows. For a groundwater sample collected from the intermediate-depth bedrock well at onsite location 01, the tracking number would be AV-GW-ON-201. The tracking number for a duplicate sample from this location would be AV-GW-ON-201D. The tracking number for a trip blank for sampling onsite groundwater on 24 August 2000 would be AV-GW-ON-A(8/24/00).

4.3.3.2 Solid Media Samples

The sample ID for solid samples will consist of a combination of the following codes, each separated by a hyphen: a site code, a management unit code, a media code, a borehole ID code, a depth code, and a QC code (for field QC samples only). The following describes each code:

- *Site code* – A two-letter identifier, **AV**, representing the Avtex site.
- *Management unit code* – A two-letter identifier, **VB**, representing the viscose basins.
- *Media code* – A two-letter code indicating that the solid sample is viscose basin material (**VM**) or a subsurface sample of soil or bedrock (**BH**).
- *Borehole ID code* – A unique location code, including two letters and a two-digit number. The borehole ID for specific-depth-interval samples from boreholes collocated with a given temporary wellpoint will be the same as the temporary wellpoint ID (e.g., WP01). If composite samples are collected from multiple boreholes, they will be identified by basin (e.g., VB09, VB10, or VB11)
- *Depth code* – A two-digit number code representing the depth at which the sample was collected. The code will use the depth of the top of the sampling interval (for example, the depth code for a surface sample collected from 0 to 0.5 ft would be 00, and the depth code for a sample collected at a depth of 12 to 14 ft below the surface would be 12). For composite samples that include multiple depths, the letters CS will be used for the depth code. Field and rinsate blank samples will use a depth code of 00.
- *Quality control (QC) code* – A single-letter code indicating that the sample is a field blank (**B**), a rinsate blank (**C**), or a field duplicate (**D**). The first two codes (i.e., B or C) will be followed by the month, day, and year that the sample was collected in parentheses [e.g., B(08/22/00) for a field blank collected on August 22, 2000]. No hyphen will be used between the depth code and the “D” QC code.

For example, a sample of waste viscose collected from the sixth viscose basin temporary wellpoint boring at a depth of 15 to 17 ft would be AV-VB-VM-WP06-15. The sample number for a field duplicate at this location would be AV-VB-VM-WP06-15D. A composite sample collected for laboratory testing from temporary wellpoint boreholes WP01, WP02, and WP03 in viscose basin 9 would be AV-VB-VM-VB09-CS.

4.4 Sample Handling and Analysis

This section describes sample-handling procedures and analytical methods that will be used for analysis of groundwater and solid samples.

4.4.1 Sample Handling and Shipping

All samples collected during this field investigation will be subjected to strict sample-handling procedures, as outlined in Section 3.3 of the QAPP (ERM 1999), to ensure that the investigation data quality objectives are achieved. Standard operating procedures for sample packaging and shipping are described in Section 5 of the QAPP (ERM 1999) and are summarized below.

Immediately after collecting each sample, the sample container, labeled with a completed sample tag, will be sealed in an individual plastic bag and placed immediately into an insulated cooler chilled to less than 4° C. Exponent COC/SAR forms will be completed at the time of sample collection and will accompany the samples inside the cooler for delivery to the analytical laboratory. A list of laboratory shipping addresses is presented in Table A-7. All shipments will be logged into the field logbook with reference to the COC/SAR form numbers contained in each sample lot. Copies of all COC/SAR forms will be submitted to the Field Team Leader (FTL) for inclusion in the field documentation files for the project.

Relinquishment of samples will be indicated on the COC/SAR form by the sampling team, and these forms will be sealed in a Ziploc bag before being placed in the cooler to protect them against moisture. Each cooler will contain sufficient ice and/or ice packs to ensure that proper temperature is maintained, and will be packed in a manner to prevent damage to sample containers. A member of the field team will then complete two custody seals and place a seal on opposite corners of each sample cooler. Examples of Exponent's Sample Tag, COC/SAR form, and Custody Seal are provided in Attachment A-9.

4.4.2 Groundwater/Pore-Water Analytical Methods

Groundwater and pore-water samples collected during the field investigation, or resulting from the laboratory testing, will be analyzed for part or all of the following parameters, depending on the sampling or laboratory testing objectives:

- Target Compound List (TCL) VOCs
- TCL SVOCs
- PCBs
- Organochlorine pesticides
- TAL inorganics
- Hexavalent chrome
- Arsenic +3/+5 speciation
- Anions (alkalinity, chloride, sulfate, and silica)

- TDS
- Ammonia nitrogen
- Chemical oxygen demand
- Density
- Field-measured parameters—pH, dissolved oxygen, Eh, temperature, specific conductance, iron speciation and turbidity (to be measured during purging).

The majority of the groundwater and pore-water samples will be submitted to Lancaster Laboratories, Inc. (LLI), Lancaster, Pennsylvania, for analysis using the analytical methods listed in Table A-8. Groundwater and pore-water samples for arsenic speciation analysis will be submitted to Frontier Geosciences, Inc., Seattle, Washington. The shipping addresses for LLI and Frontier Geosciences are listed in Table A-7. The specific analyses for groundwater and pore-water samples collected from monitoring wells and temporary wellpoints to characterize site water quality are summarized in Table A-3. The analyses to be performed on samples derived from laboratory testing are summarized below.

4.4.3 Laboratory Testing Methods for Aqueous Samples

Groundwater and/or pore-water samples will be collected during the supplemental field investigation for use in carbon disulfide hydrolysis laboratory testing and electrical resistance heating laboratory testing/characterization. The following summarizes the procedures for these tests.

4.4.3.1 Carbon Disulfide Hydrolysis Tests

Seven samples of groundwater/pore water, each consisting of three VOA vials, will be collected from the wells/temporary wellpoints cited in Section 4.1.1 for use in carbon disulfide hydrolysis testing. In addition, six 500-mL septum-sealed amber glass bottles will be filled from each of the wells/temporary wellpoints. Prior to collection of the samples, three of the VOA sets and three of the 500-mL bottles will be spiked with 0.2, 2.0, and 4.0 mL of 30 percent hydrogen peroxide. Once all of the sample bottles have been filled and sealed, they will be placed in a cooler (at 4°C) and shipped to Columbia Analytical Services (CAS) in Kelso, Washington. At the laboratory, the VOA vial sets that were spiked with hydrogen peroxide, as well as one VOA vial set that was not spiked with hydrogen peroxide, will be analyzed for carbon disulfide. In addition, the three 500-mL bottles that were spiked with hydrogen peroxide, and one 500-mL bottle that was not spiked, will be analyzed for TAL inorganics, alkalinity, chloride, sulfate, silica, and pH. The samples from each well will be stored at the laboratory in the dark at a constant temperature similar to that of the site groundwater. The remaining VOA vial sets will be analyzed after 1, 3, and 6 months for carbon disulfide. One of the remaining 500-mL

bottles will be analyzed for TAL inorganics, alkalinity, chloride, sulfate, silica, and pH after 6 months. Analytical methods are summarized in Table A-7. Groundwater in the final 500-mL bottle will be filtered through a 0.45- μ m filter. If sufficient precipitate is collected (0.5 g), it will be evaluated by x-ray diffraction (XRD) to identify any crystalline compounds (particularly metal sulfides) that precipitated during the hydrolysis experiment. Powder XRD analysis will be conducted using a Scintag PAD 5 x-ray diffractometer at the Department of Geological Sciences, University of Colorado at Boulder (see Attachment A-10).

4.4.3.2 Electrical Resistance Heating Tests

To evaluate electrical resistance heating (ERH) as a potential remedial technology, viscose basin pore-water samples will be collected from temporary wellpoints WP01, WP04, and WP07 (three samples total) for static electrical conductivity analyses. These analyses will be performed under the direction of Applied Hydrology Associates, Inc. (AHA), of Denver, Colorado. A summary of the testing is contained in Attachment A-11. The pore-water samples will be sent to McMillan-McGee (MC2)—AHA's subcontract laboratory—in Calgary, Alberta, Canada at the address shown in Table A-7.

4.4.4 Viscose Solid Media Analytical and Laboratory Methods

This section discusses the chemical and physical evaluation of solids samples collected from viscose basins 9, 10, and 11 that will be performed as part of the supplemental field investigation.

4.4.4.1 Chemical Characterization

To determine chemical characteristics of the waste material in the viscose basins, a total of 18 samples will be collected and submitted to LLI for analysis for TCL VOCs, TCL SVOCs, TAL inorganics, paste pH, anions (chloride, silica, and sulfate), ammonia nitrogen, and percent solids using the analytical methods presented in Table A-8. All samples will be submitted to LLI at the address shown in Table A-7.

4.4.4.2 Hydrologic Parameters

To determine hydrologic properties of the waste material in the viscose basins, 12 samples will be submitted to GeoSyntec Consultants (GSC) in Atlanta, Georgia for analysis of field capacity, wilting point, vertical hydraulic conductivity, porosity, moisture content, and bulk density. In addition, three samples of overburden will be submitted to GSC for measurement of vertical hydraulic conductivity. Methods for these analyses are presented in Table A-9. All samples shall be submitted to GSC at the address shown in Table A-7.

4.4.4.3 Consolidation and Shear Testing

To gain an understanding of the consolidation properties and shear strength of the waste viscose material, nine undisturbed core samples (Shelby tubes) will be submitted to GSC for consolidation tests using ASTM method D2435-96 and Vane Shear tests using ASTM method D4648-94 (Table A-9; Attachment A-3). To obtain additional information on the amount of water released from the waste viscose during consolidation pressures, GSC will be requested to record the amount of water expelled from the test apparatus during each pressure increment. All samples collected for testing by GSC shall be submitted to the address shown in Table A-7.

During selected consolidation tests, samples of the pore water released at each successive loading increment will be collected for analysis of TCL VOCs, and a composite of the water released over the duration of the test will be collected for analysis of TAL inorganics, alkalinity, pH, TDS, sulfate, chloride, and silica. It is possible that the samples may require dilution to produce sufficient water for these analyses. In addition, samples of the waste viscose will be collected following the completion of the testing and submitted to the analytical laboratory for the chemical characterization analyses described in Sections 4.4.4.1 and 4.4.4.5. The results of these chemical analyses will provide an indication of the potential for chemicals to be released from the waste viscose under compressive force. All of the sample chemical analyses will be performed by LLI, with the exception of the quantification of free and bound carbon disulfide, which will be performed by CAS.

4.4.4.4 Electrical Resistance Heating Tests

To evaluate electrical resistance heating as a potential remedial technology, a total of nine undisturbed cores of viscose waste material will be collected (Table A-6) from temporary wellpoints WP01, WP04, and WP07 (three samples from specific depth intervals in each borehole). The results of the electrical resistivity laboratory tests will be evaluated by Applied Hydrology Associates, Inc. (AHA), of Denver, Colorado. A summary of the testing that will be performed by AHA is contained in Attachment A-11. AHA uses a subcontract laboratory—McMillan-McGee (MC2) of Calgary, Alberta, Canada—to measure the electrical resistance of the samples. Therefore, the nine cores will be shipped to MC2 at the address shown in Table A-7, and MC2 will perform the measurements under the direction of AHA.

4.4.4.5 Quantification of Free and Bound Carbon Disulfide in Waste Viscose

A sequential extraction procedure will be used to quantify the concentration of carbon disulfide in waste viscose that is present in free and bound forms. The sequential extraction procedure will be performed by Columbia Analytical Services (CAS) following the procedures in Attachment A-12. All leachates will be analyzed using

purge-and-trap (EPA method 5050A) and GC/MS analysis (EPA method 5030B). In addition, splits of each sample will be analyzed both prior to and following the sequential extraction by Fourier transform infrared spectroscopy (FTIR) at R.J. Lee Group, Inc. in Monroeville, Pennsylvania. These analyses will provide a semi-quantitative analysis of the relative abundance of carbon disulfide bound to the cellulose matrix (i.e., present as cellulose xanthate) before and after extraction. Specific methods for conducting the FTIR analysis are provided in Attachment A-13.

4.4.4.6 Waste Viscose Hydroxide Liberation Tests

Laboratory tests will be conducted to quantify the extent to which the viscose basins represent a source of hydroxide ions to groundwater, as well as the acid requirements to neutralize the waste viscose. A total of nine waste viscose samples will be collected during the supplemental field investigation and shipped to Exponent's Boulder, Colorado laboratory for these tests. The procedures for this test are presented in Attachment A-14.

4.4.4.7 Waste Viscose Laboratory Treatability Studies

Laboratory treatability studies (Section 6.3 of the FS Work Plan) that are intended to evaluate the effectiveness of various remedial technologies or actions will be performed using the composite waste viscose samples collected from each basin. The composite sample buckets will be shipped to Exponent's Boulder, Colorado testing laboratory (Table A-7). Prior to the sampling effort, a Laboratory Testing and Analysis Plan (LTAP) that provides detailed experimental and quality control procedures will be prepared and submitted for approval.

Proposed laboratory treatability studies include the following:

- Waste viscose chemical oxidation tests
- Waste viscose vermiculture treatment tests
- Testing of physical and chemical techniques to improve the handling properties of the waste viscose.

5. Synoptic Static Water-Level Measurement and Geologic Mapping

A synchronized measurement of the static water levels will be made in on- and offsite wells and temporary wellpoints to characterize the groundwater potentiometric surface in the overburden and bedrock geologic units. These measurements will be completed a minimum of two weeks after sampling and field testing of all monitoring wells and temporary wellpoints to allow the groundwater levels to stabilize across the site. Equipment requirements are listed in Attachment A-4.

In addition, the orientation of cleavage and bedding planes in bedrock outcrops southwest of the Avtex site will be mapped by a geologist.

5.1 Synoptic Static Water-Level Measurement

Groundwater levels will be measured in all proposed and accessible existing onsite/offsite wells (potentially a total of 109 wells) and all 28 temporary wellpoints. Figure A-7 provides the locations of the 9 proposed wells and the 100 existing wells in the onsite/offsite monitoring well network. The locations of the 14 Geoprobe[®] temporary wellpoints are shown in Figure A-1. The approximate locations of the nine proposed viscose basin temporary wellpoints and the five proposed overburden temporary wellpoints are indicated in Figure A-2.

Static water levels will be measured using an electronic water-level instrument following the procedures in SOP 19 (Attachment A-5). Water-level measurements will be recorded to the nearest 0.01 ft in the field notebook. Decontamination of depth-to-water meters is described in SOP 19. Monitoring well/wellpoint IDs for the 137 synoptic water-level measurements are listed in Tables A-1a, A-1b, and A-2.

5.2 Geologic Mapping

A geologist using a Brunton compass will map the orientation of cleavage and bedding planes in bedrock outcrops southwest of the Avtex site. In addition to mapping outcrops in the hills southwest of Rivermont Acres, an effort will be made to map outcrops that are exposed above the surface of the Shenandoah River during low flow. The strike and dip of the structural features in the outcrops will be used to understand the cleavage and the orientation and folding of beds, particularly with respect to the anticline that appears to provide important structural control on the movement of the dense carbon disulfide plume.

6. Field Tests

Two field tests will be performed during the supplemental field investigation: single-well pumping tests and infiltrometer tests. These tests are summarized below.

6.1 Single-Well Pumping Tests

Single-well, constant-rate pumping and recovery tests will be performed in three temporary wellpoints installed in the viscose basins (one each in basins 9, 10, and 11) and in four selected overburden monitoring wells/temporary wellpoints, to provide estimates of horizontal hydraulic conductivity. Specific test locations will be determined after the new monitoring wells and temporary wellpoints have been installed and developed. The pumping tests will be performed in general accordance with SOP 36, modified for the lower pumping rates that are expected to be required for these tests. Equipment requirements are presented in Attachment A-4.

6.1.1 Pre-Test Monitoring

Before conducting each constant-rate test, groundwater elevations in the test well will be monitored continuously for a period of 24 hours. Barometric pressure will also be measured throughout the 24-hour pre-test monitoring period, as well as throughout the constant-rate test and the recovery period. These data will allow barometric pressure effects on groundwater levels to be distinguished from those induced by the pumping test.

6.1.2 Pumping Test

A 4-hour (minimum) constant-rate aquifer pumping test will be conducted at each of seven selected temporary wellpoint locations. Pumping rates will be selected based on the sustainable pumping rates from each location observed during development of the temporary wellpoints. It is anticipated that the sustainable pumping rates may be very low (e.g., less than 1 gpm). The pump inlet will be set at a depth of approximately 5 ft above the bottom of the temporary wellpoint. The water surface elevation in the temporary wellpoint will be monitored continuously throughout both the pumping and recovery portions of the test using pressure transducers and automatic electronic data loggers, as described below.

Submersible pumps, a power supply, and discharge piping and valves will be necessary for the constant-rate pumping tests. The pumps and plumbing will be installed and operated according to the general configuration indicated in Figure A-8. Depending on the required flow rate, either a peristaltic pump or a submersible pump will be used for

each test. All plumbing will be located where it does not interfere with, or could be damaged by, other activities at the site.

The discharge rate and volume from the pumps will be monitored using a calibrated, in-line flow meter and totalizer, and the discharge rate from the pump will be maintained using either a variable-speed pump or a gate valve (or equivalent) to check flow (Figure A-8). Flow rate will be monitored, and if necessary, adjusted at 1-, 10-, and 30-minute intervals during the 0–10, 10–30, and 30–240 minute periods of the test, respectively. Flow rate will be recorded in the field logbook or pumping test field forms for each of these time intervals.

6.1.3 Recovery Test

Following the constant-rate pumping period, the pump will be shut off, and the groundwater elevations will continue to be recorded for an additional 4-hour (minimum) water-level recovery period, or until the groundwater elevation in the pumping well returns to its pre-test elevation.

6.1.4 Water-Level Measurement and Recording

The water level in the temporary wellpoint will be monitored throughout the pre-test monitoring period, constant-rate pumping test, and recovery test using pressure transducers connected to data loggers. Transducers will be installed approximately 1 ft above the top of the pump inlet. The transducer will be connected to an electronic data logger. The frequency of data collection will decrease with time during both the pumping and recovery phases of the test, as discussed in SOP 36. Backup measurements will be taken using an electronic water-level indicator at a frequency appropriate for the degree of change in water level during the test, in accordance with SOP 19.

6.1.5 Discharge and Treatment of Water Produced During Aquifer Testing

Water pumped from each temporary wellpoint during the tests will be discharged to a trailer- or truck-mounted storage container (or other appropriate container) with sufficient capacity for the total volume of water produced during each test. The discharge water will then be transported to the viscose leachate digester (see Figure 2-5 of the FS Work Plan), from which it will be transferred to the onsite wastewater treatment plant (WWTP) for treatment.

6.1.6 Documentation

Groundwater elevations and barometric pressure will be recorded electronically using an automatic data logger. The monitoring point location, relative benchmark for depth measurements, equipment used, and test identification number used in the data logger

will be noted in the log book. Measurements of the flow rate and method of measurement, and any manual water-level measurements, will be recorded in the logbook. At the end of each test, the data stored in the logger will be downloaded to a laptop computer and placed on a backup floppy disk. The supervising hydrogeologist will also document all field activities, including local weather conditions, personnel on site, and any deviations from this work plan.

6.1.7 Data Evaluation

Drawdown and recovery data will be analyzed to estimate aquifer properties using standard aquifer test analysis techniques (e.g., the methods of Theis, Cooper and Jacob, Hantush, and Neumann; SOP 36). Because the applicability of these solution techniques is highly site specific, the method to be applied during this investigation will be selected based on aquifer conditions at the site and a preliminary review of the pumping test data.

6.2 Infiltrometer Tests

In-situ infiltrometer tests will be conducted in viscose basins 9, 10, and 11 to characterize the macro-scale infiltration properties of the basins. The infiltrometer tests will be performed in general accordance with ASTM Method D3385-94—Standard test method for infiltration rate of soils in field using double-ring infiltrometer (provided in Attachment A-3). This method will be modified to use large-diameter (0.5 to 2 m), single-ring tests, because double-ring tests tend to overestimate the infiltration rate (Bouwer *in* Wilson et al. 1995). A total of nine tests will be performed—three tests in each of viscose basins 9, 10, and 11—to account for heterogeneity within the basins. Specific test locations will be selected in the field after completing a visual examination of the surface of each basin.

6.2.1 Test Procedures

The ring diameter for each test will be chosen to be large enough to incorporate variability in surface characteristics but not so large as to require an unreasonable amount of water to perform the tests. Testing procedures will follow ASTM D3385-94, except that only a single ring will be used. In the event that the ring cannot be driven to a minimum of 6 inches below the bottom of the surficial crust layer of the viscose basins, the crust layer will be removed prior to testing. Mariotte tubes will be used to maintain a constant head in the infiltrometer. An equipment list for this test method is provided in the ASTM method.

Field installation procedures will be documented in the logbook. Time, water level in the ring, and water supply rate will be documented in accordance with the data sheet format in ASTM method D3385-94. The volume of fluid that infiltrates during each measured time interval will be converted to an incremental infiltration velocity using the equations

in the ASTM method. Results from each test will be evaluated and used to calculate a mean and standard deviation for the infiltration rate at each test location.

7. Supplement to the Quality Assurance Project Plan

This section presents information that supplements the QAPP (ERM 1999). The information presented here is specific to this investigation and thus is not addressed in detail in the QAPP. References to specific QAPP sections are provided, as necessary.

7.1 Project/Field Team Organization

This section describes the organization of project and field teams for this field investigation (Section 2.1 of the QAPP). An organizational chart is presented in Figure A-9. All onsite activities will be conducted under the direction of the Field Team Leader (FTL). A designated Field Task Manager (FTM) reporting to the FTL will be designated for each sampling team and will be responsible for performing the specific sampling tasks and related activities in accordance with the QAPP and this FSAP. The Site Safety Officer (SSO) will be responsible for ensuring compliance with the Exponent Health and Safety Plan (HSP).

Two-person teams of experienced environmental sampling technicians will conduct the groundwater/pore-water sampling. Each sampling team will have a designated FTM responsible for implementing the requirements of the QAPP and this FSAP, including the sampling activities (sample collection, identification, labeling, handling, packaging, documentation and shipping), and for maintenance of a bound field notebook that provides the FTL with daily reports of field team activities. Under the SSO's direction, the FTM will also be responsible for ensuring that the team implements the appropriate health and safety procedures at each sampling location.

The viscose basin borehole and temporary wellpoint installation will be performed by a drilling company with a registered contractor's license in the State of Virginia, under the direction of a two-person Exponent team consisting of a hydrogeologist and a sampling technician. The Exponent team will perform all sampling. The hydrogeologist will serve as the FTM and will be responsible for conducting the investigation in accordance with its stated objectives, completing the boring logs and field log book, and conducting health and safety monitoring during sampling activities under the direction of the SSO or designee. The sampling technician will assist the FTM in sample collection, identification, handling, packaging, and documentation.

7.2 Critical Data Quality Indicators and Associated Performance Criteria

This section presents critical data quality indicators (DQIs) required per Section 2.5 of the QAPP. Table A-8 presents a summary of analytical methods by matrix and includes DQIs for bias, precision, and completeness. Quantification limits for the methods for VOCs, SVOCs, PCBs, TAL inorganics, and conventional analytes are presented in

Tables A-10 through A-15. Criteria for all other investigation DQIs not presented in this document are contained in the QAPP.

7.3 Sample Containers and Preservatives

All sample containers with preservatives, as appropriate for specific analyses, will be provided by the analytical laboratory (i.e., LLI). Table A-4 summarizes the types and sizes of sample containers, preservative requirements, and holding times for the analytes for this field investigation.

To address the majority of the DQOs presented in Section 2.2, 100 percent of the samples for analysis of Target Level IV analytes will be collected. Broken or lost samples will be replaced. Furthermore, if a well cannot be sampled due to damage, the well will be repaired or replaced, or an alternative, representative well will be selected (in conjunction with the EPA) and sampled. Exponent will evaluate well conditions during the week of June 19, 2000.

7.4 Documentation of Field Activities

A record of field activities will be maintained using bound, weatherproof field notebooks and/or numbered field data forms in accordance with the procedures described in Section 3.3.1 of the QAPP (ERM 1999). The field notebooks and field data forms will be maintained by the FTL or designee. All field records, data, field notebook pages, COC/SAR forms, drilling logs, and other reports will be sent to the Project Manager at the completion of field activities for inclusion in the project files.

The FTL or designee, as appropriate, will maintain a record of field activities in a bound, weatherproof field notebook(s). All appropriate information related to sampling activities must be recorded in the field notebook.

At the end of each day, the FTL or designee will review the documentation for accuracy and completeness. If problems are noted, the appropriate FTM(s) will be directed to address them. In addition, the SSO will complete a daily field safety meeting to discuss and address pertinent health and safety issues. As specified in Section 4 of the QAPP (ERM 1999), a single field audit will be completed by the FTL. This field audit will occur during the groundwater sampling event.

7.5 Decontamination

Prior to mobilizing to the site to conduct ground water sampling, all bailers will be decontaminated off site at Exponent's laboratory in Boulder, Colorado using the following procedure:

- Potable water rinse

- Liquinox detergent wash
- Potable water rinse
- 10 percent nitric acid solution rinse
- Distilled or deionized water rinse
- Methanol rinse
- Deionized water rinse
- Air dry
- Butcher paper wrap.

All purging and sampling equipment to be used at multiple sampling locations will be decontaminated in the field prior to beginning purging and sampling activities, after use in each monitoring well, and before leaving the Avtex site. All decontamination fluids will be contained and transported to the viscose leachate digester (see Figure 2-5 of the FS Work Plan) for disposal (water), or will be disposed of according to local regulations (acetone and hexane).

Purging and sampling equipment will be decontaminated using procedures appropriate for the type of equipment being decontaminated (e.g., steam cleaning, hand wash and rinse with appropriate materials, etc.). The probes and cables of the depth-to-water meters will be decontaminated per SOP 19.

Submersible pumps will be decontaminated by pumping a Liquinox solution through the pump and scrubbing the exterior of the pump with the Liquinox solution and a bristle brush. The pump will then be rinsed with tap water, followed by pumping tap water through the pump. Distilled water will then be pumped through the pump, completing the decontamination procedure.

Any equipment that cannot be decontaminated or is designated for one-time use (e.g., tubing) will be properly packaged and disposed of, as described below. Health and safety monitoring instruments will be decontaminated by wiping with a damp cloth. If gross contamination of health and safety monitoring instruments is likely, the instruments will be wrapped in plastic bags prior to use.

All sampling personnel will pass through a Contamination Reduction Zone that will be established for each monitoring well or well nest. The level of personal decontamination required will depend on the level of protection necessary to complete sampling activities at each location. Details are provided in the site-wide health and safety plan (FMC 2000), and the health and safety plan addendum (Attachment A-1).

The drilling rig and drilling and sampling tools (split-spoon samplers, Shelby tubes, continuous-driven samplers, etc.) will be decontaminated by initially washing with high-

pressure steam. The equipment will be decontaminated after each boring, and before it leaves the site. Decontamination will be performed at a temporary decontamination pad, located near the drilling rig. Water generated from decontamination will be contained and staged in a designated area.

Sampling equipment such as split-spoon samplers, Shelby tubes, continuous-driven samplers, soil scoops, stainless steel bowls, and trowels will be decontaminated in accordance with the procedures outlined in the first paragraph of this section.

7.6 Management of Investigation-Derived Wastes

All water generated during well purging and equipment decontamination will be collected in an appropriate container, and transported and discharged to the viscose leachate digester. Large volumes of water (e.g., drilling fluids and development/purge water) will be collected in a truck- or trailer-mounted containment system (e.g., a Baker tank), which will be periodically drained to the viscose leachate digester. A contractor certified for the transport of hazardous materials will transport any water generated during development, purging, and/or sampling of offsite monitoring wells. Any free-phase liquids other than water that are derived from any well/wellpoint will be appropriately contained and labeled for temporary onsite storage until the material can be identified and disposed of properly.

Contaminated personal protective equipment (PPE) and disposable sampling equipment will be contained in double plastic bags, which will be sealed with duct tape and marked to indicate the date, contents, and sampling location. PPE must be separated from disposable sampling equipment. All double-bagged and labeled PPE and disposable sampling equipment will be stored in the designated onsite storage area until it is properly characterized and disposed of offsite. Solid wastes generated during the investigation (e.g., paper towels and PPE) will be cleansed of any gross soil accumulation or contaminants and will be placed in plastic garbage bags and double-bagged for disposal at a municipal landfill.

Waste viscose and soil generated during the drilling in viscose basins 9, 10, and 11 will remain where it is generated (i.e., on the surface of the basins). Upon completion of each borehole, the solids will be spread out over the basin surface, such that the surface will be returned to pre-drilling contours. Soils and rock generated during the installation of wells and temporary wellpoints (those outside of the viscose basins) will be contained at the well/wellpoint and transported and deposited on the surface of viscose basin 9, 10, or 11.

7.7 Site Health and Safety Procedures

Specific health and safety procedures for this field investigation are presented in a site-wide health and safety plan (FMC 2000) and a health and safety plan addendum (Attachment A-1). All field staff will be supplied with copies of both documents and will

receive onsite training on the existing hazards and safety procedures before the field activities begin.

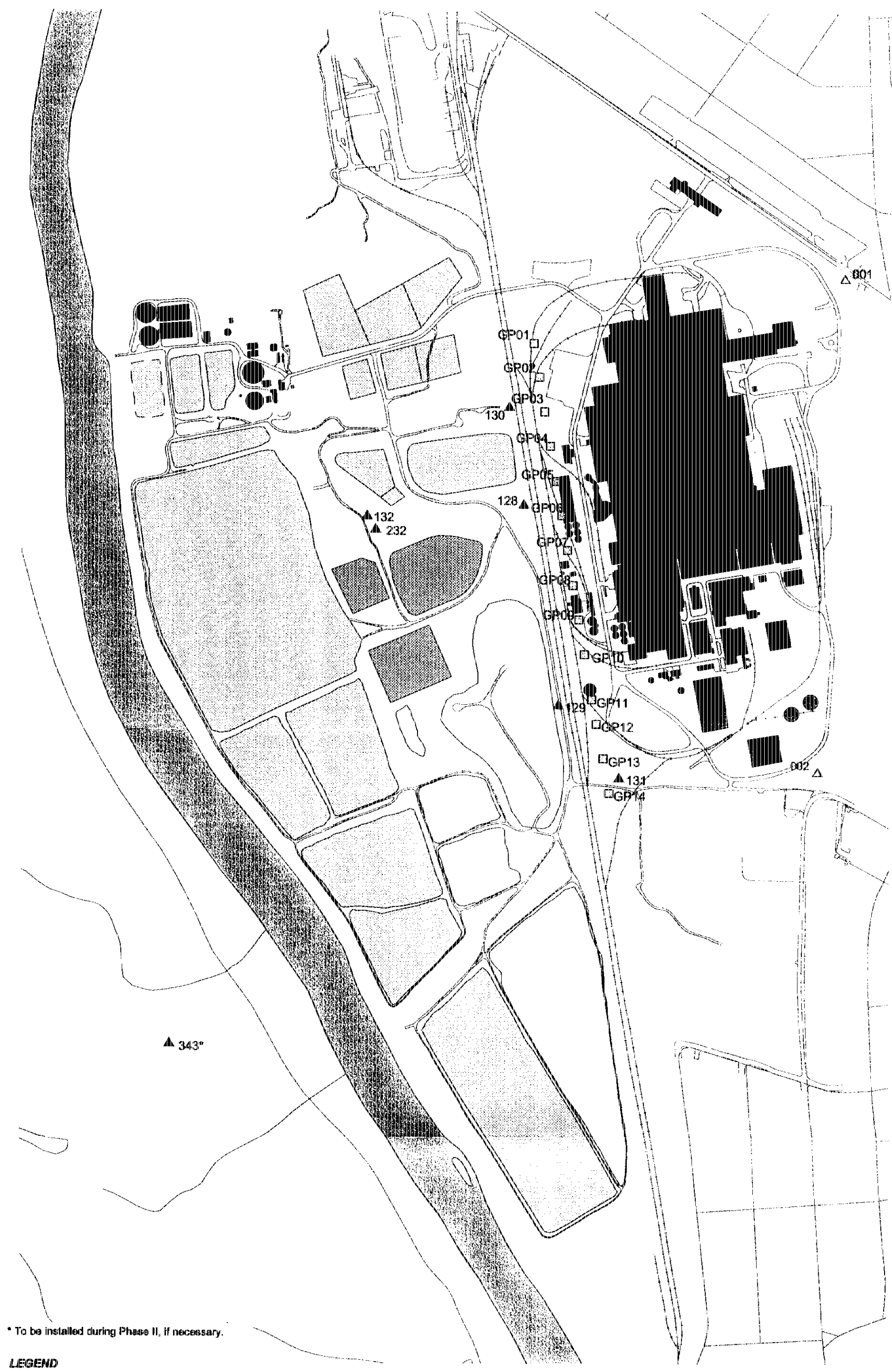
8. References

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Figures

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AR301937



* To be installed during Phase II, if necessary.

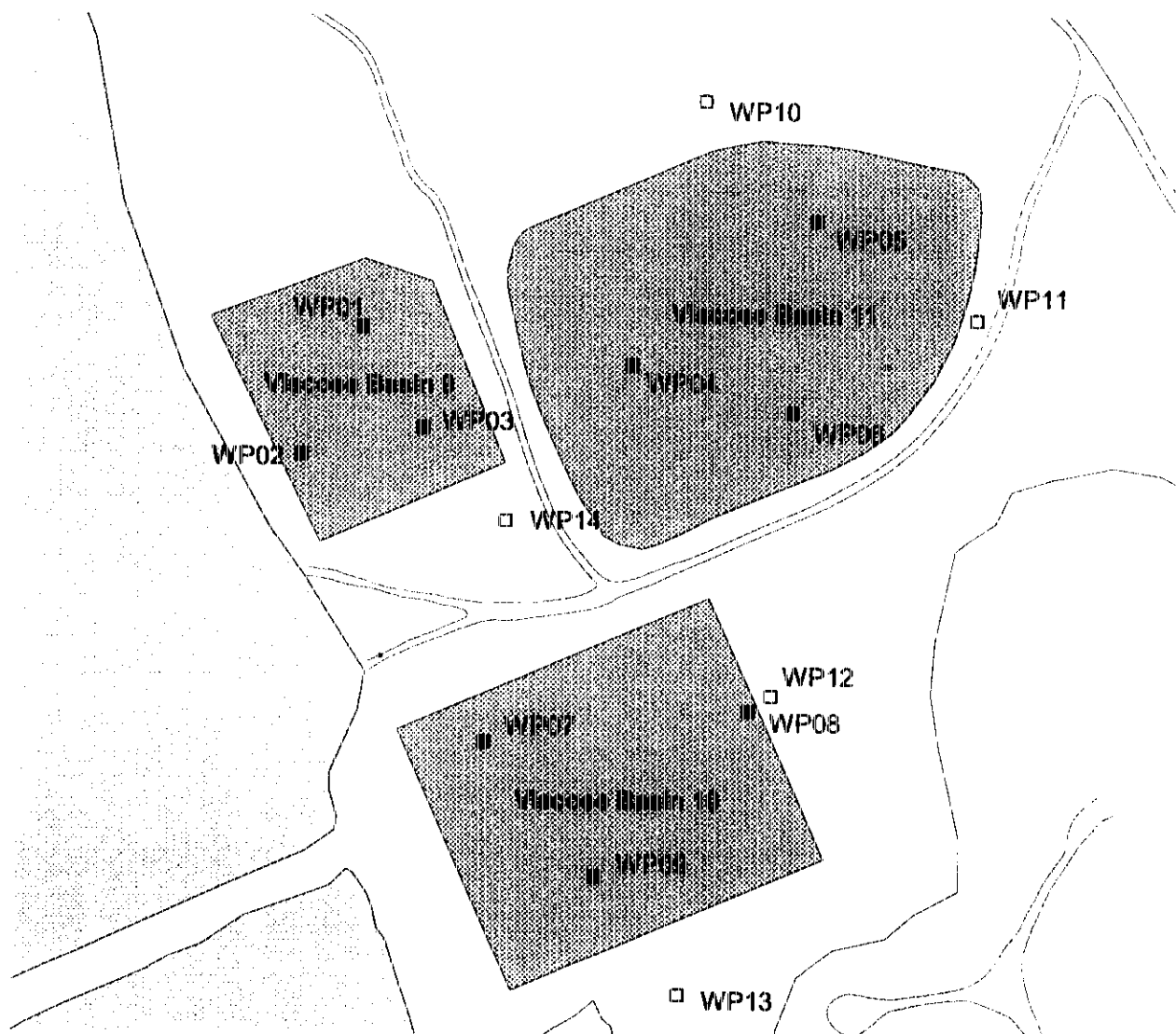
LEGEND

- Proposed Overburden Geoprobe Sampling Location (GP01 - GP14)
- △ Proposed Overburden Well
- ▲ Proposed Shallow Bedrock Well
- ▲ Proposed Intermediate Bedrock Well
- ▲ Proposed Deep Bedrock Well



0 500 1000 Feet

Figure A-1. Locations of proposed groundwater monitoring wells and Geoprobe sampling locations.



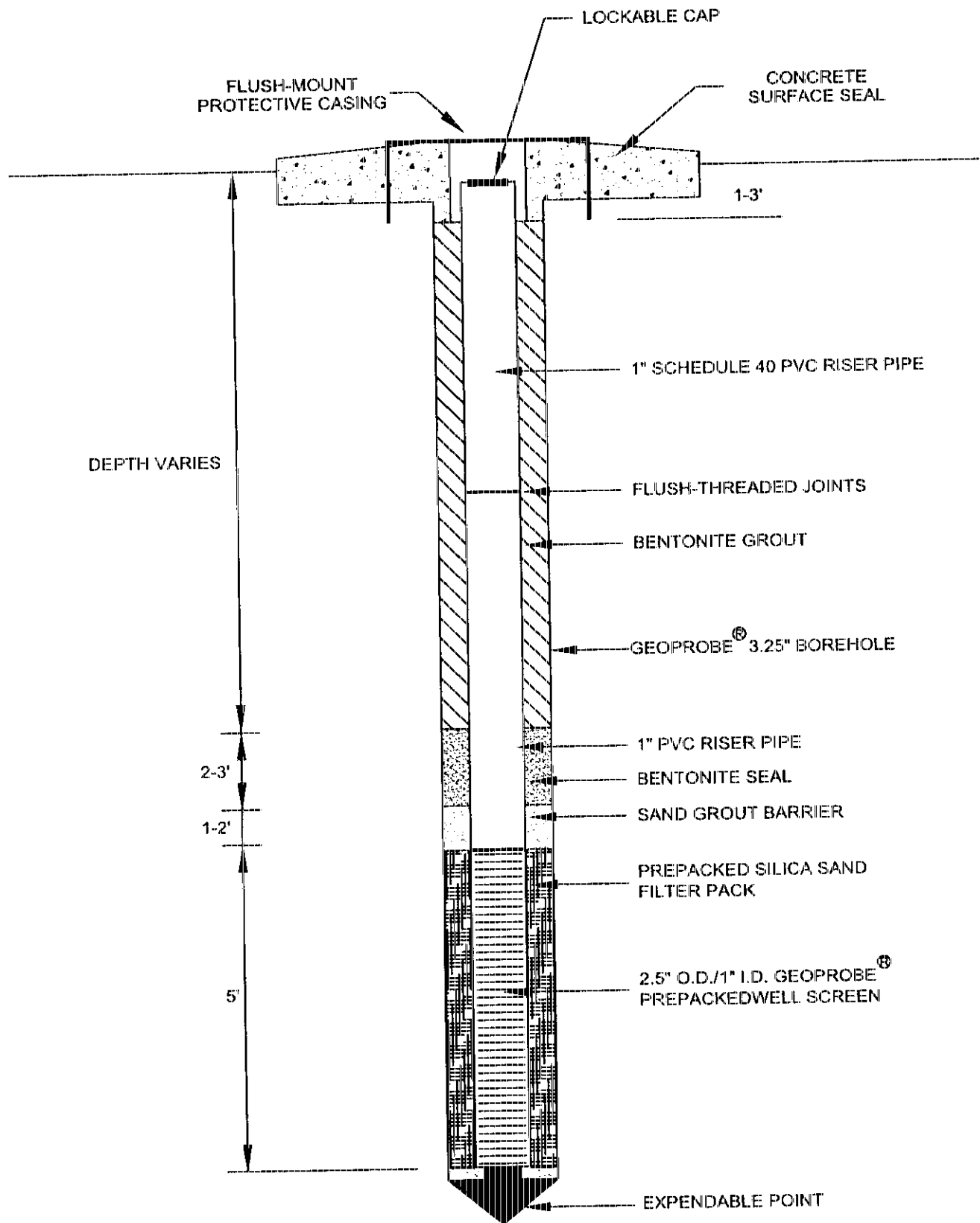
LEGEND

- Proposed Viscose Basin Temporary Wellpoint
- Proposed Overburden Temporary Wellpoint



0 100 200 Feet

Figure A-2. Proposed locations for temporary wellpoint installation and borehole core sampling.



NOT TO SCALE

Figure A-3. Geoprobe® temporary wellpoint design.

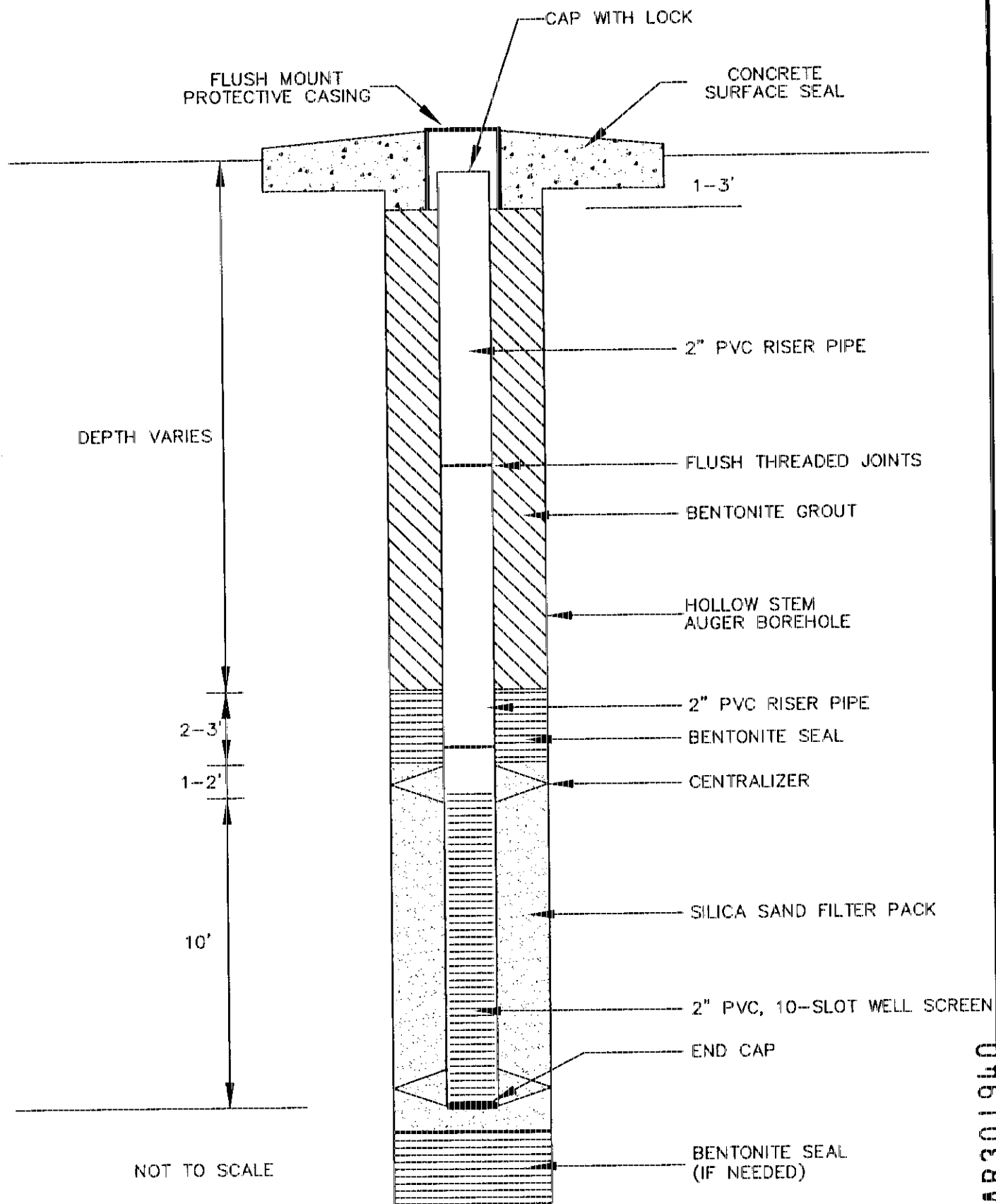


Figure A-4. Typical overburden monitoring well or temporary wellpoint design.

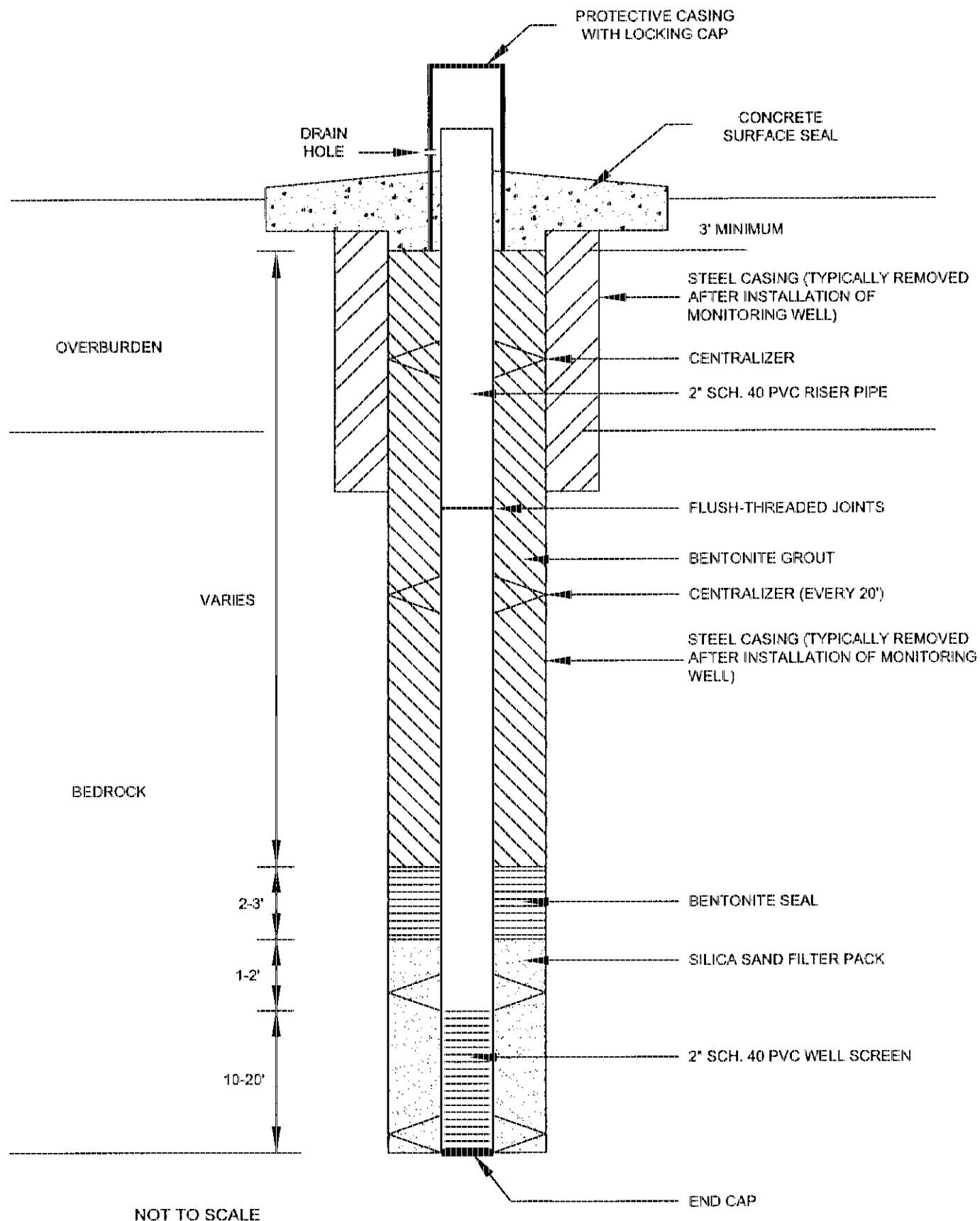


Figure A-5. Typical bedrock well design.

AR301941



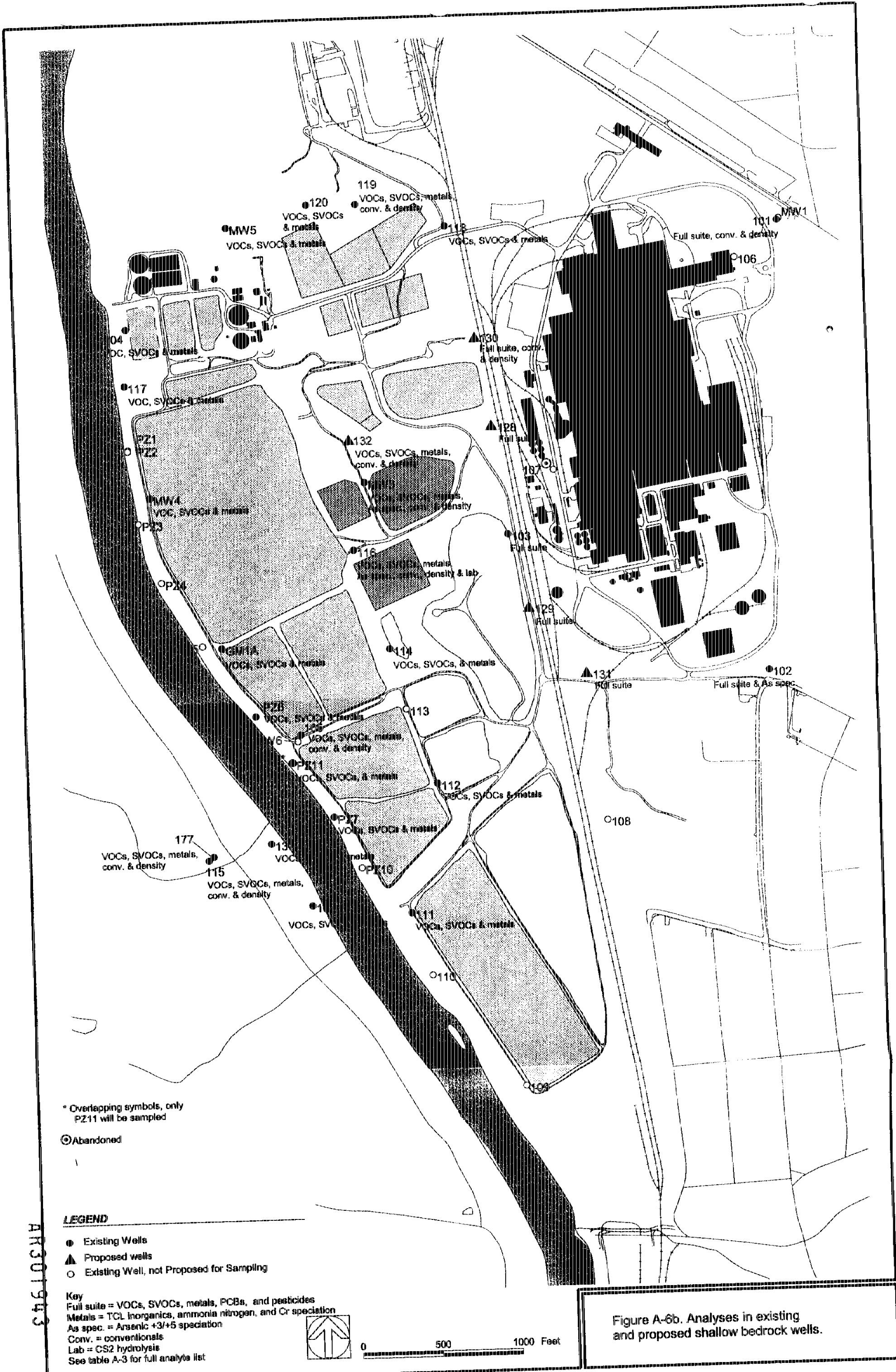


Figure A-6b. Analyses in existing and proposed shallow bedrock wells.

AR301943

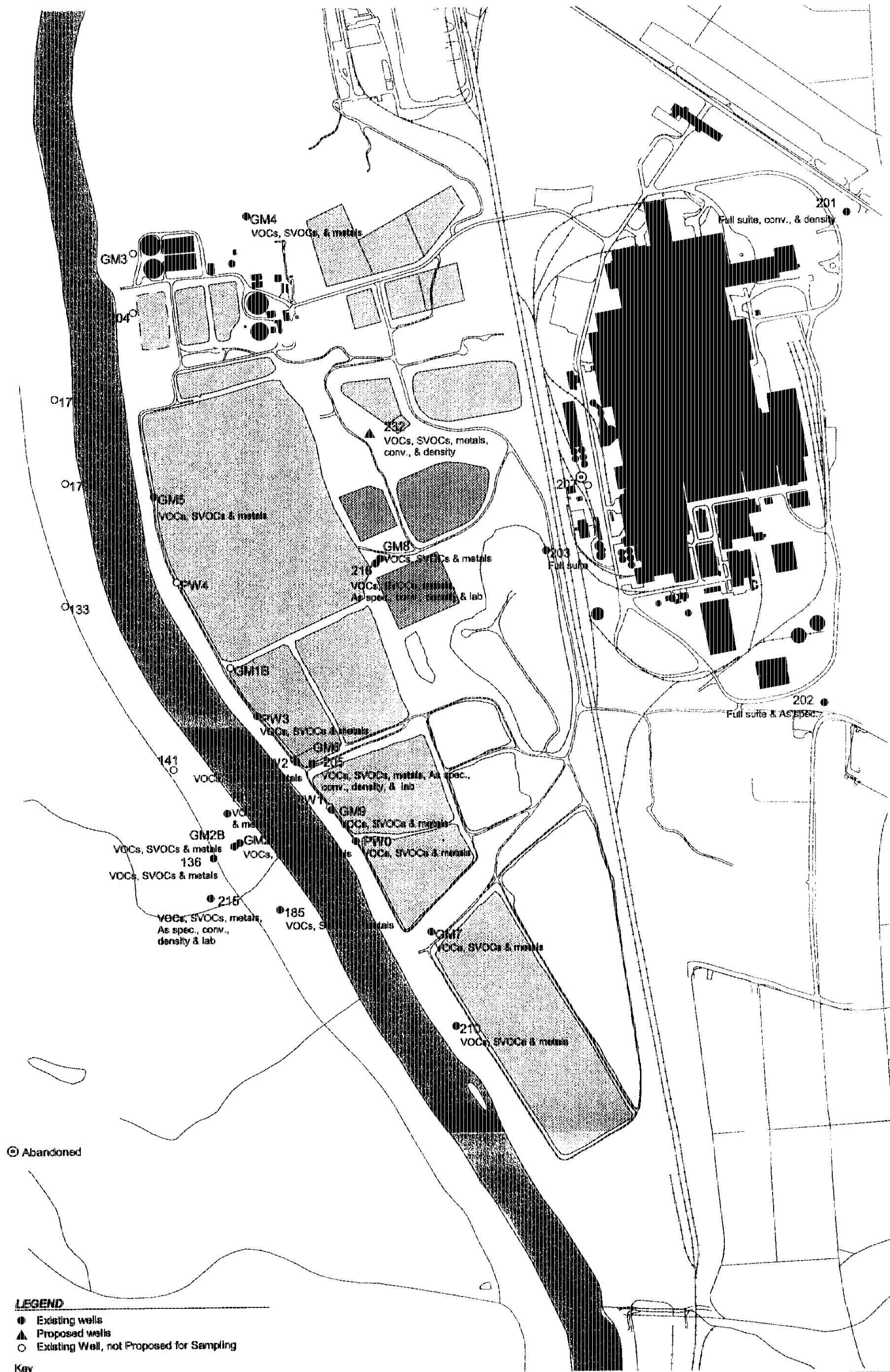


Figure A-6c. Analyses in existing and proposed intermediate bedrock wells.

AR301945

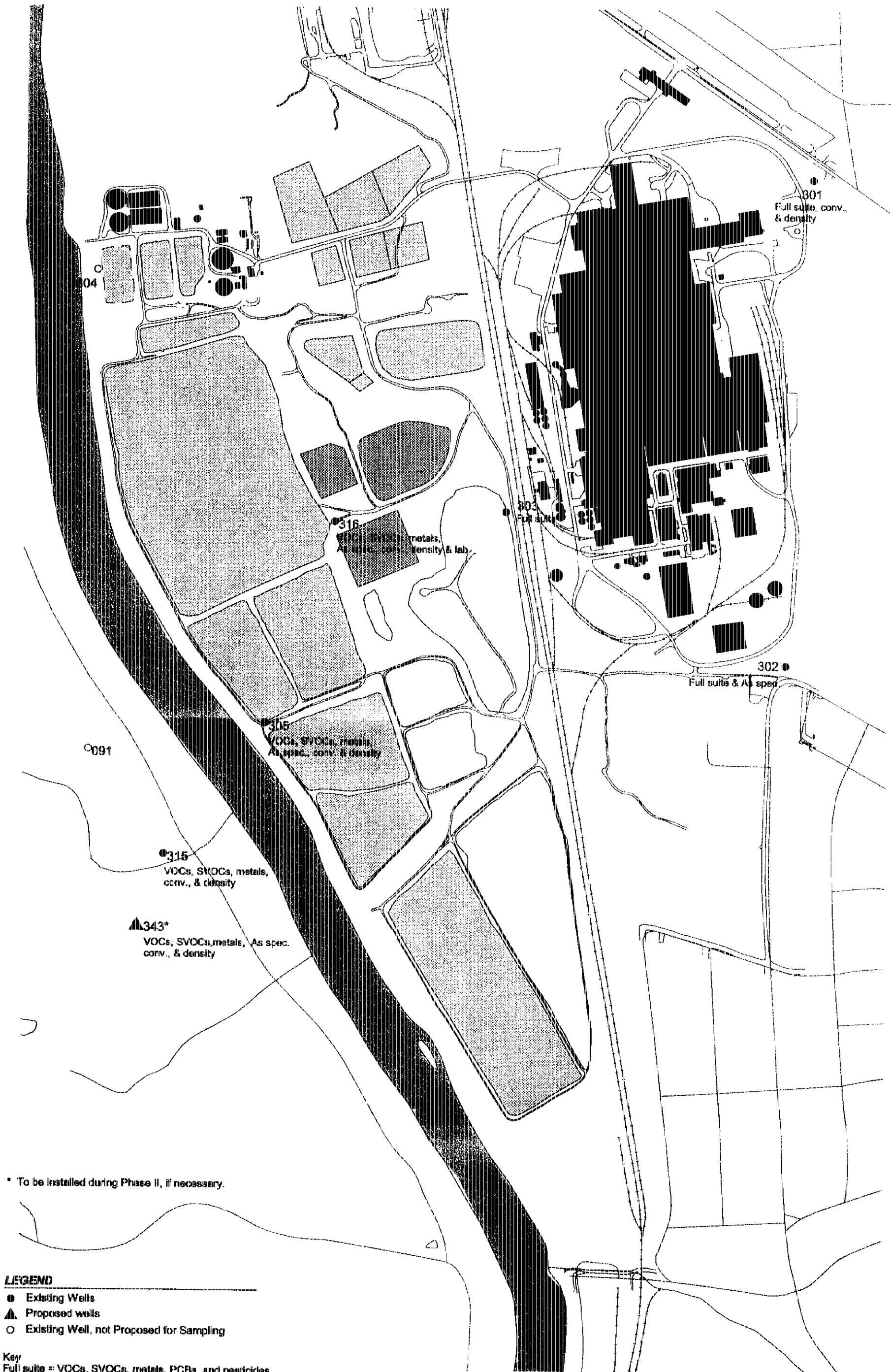


Figure A-6d. Analyses in existing and proposed deep bedrock wells.

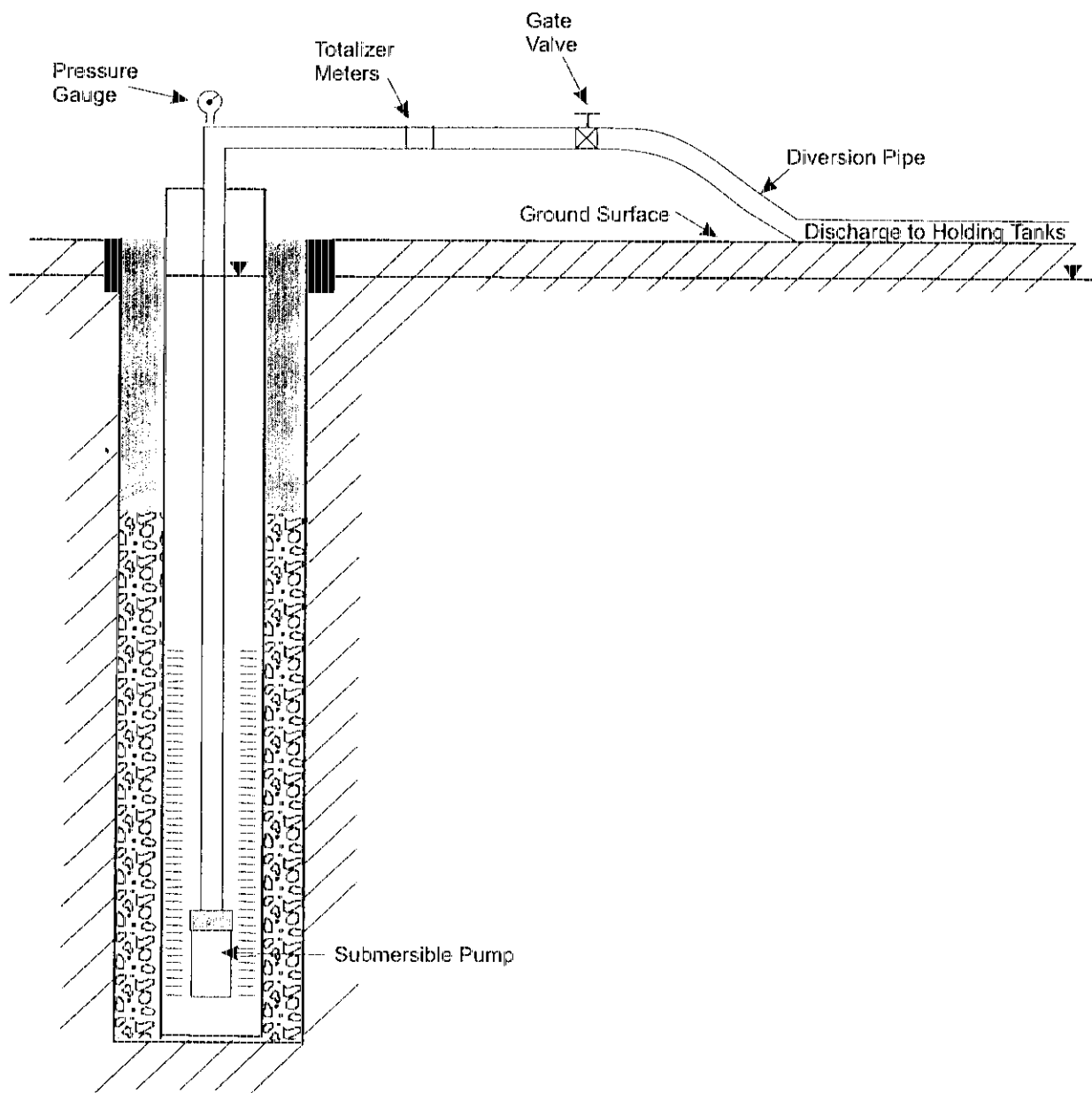


Figure A-8. Schematic of aquifer test pump and plumbing configuration.

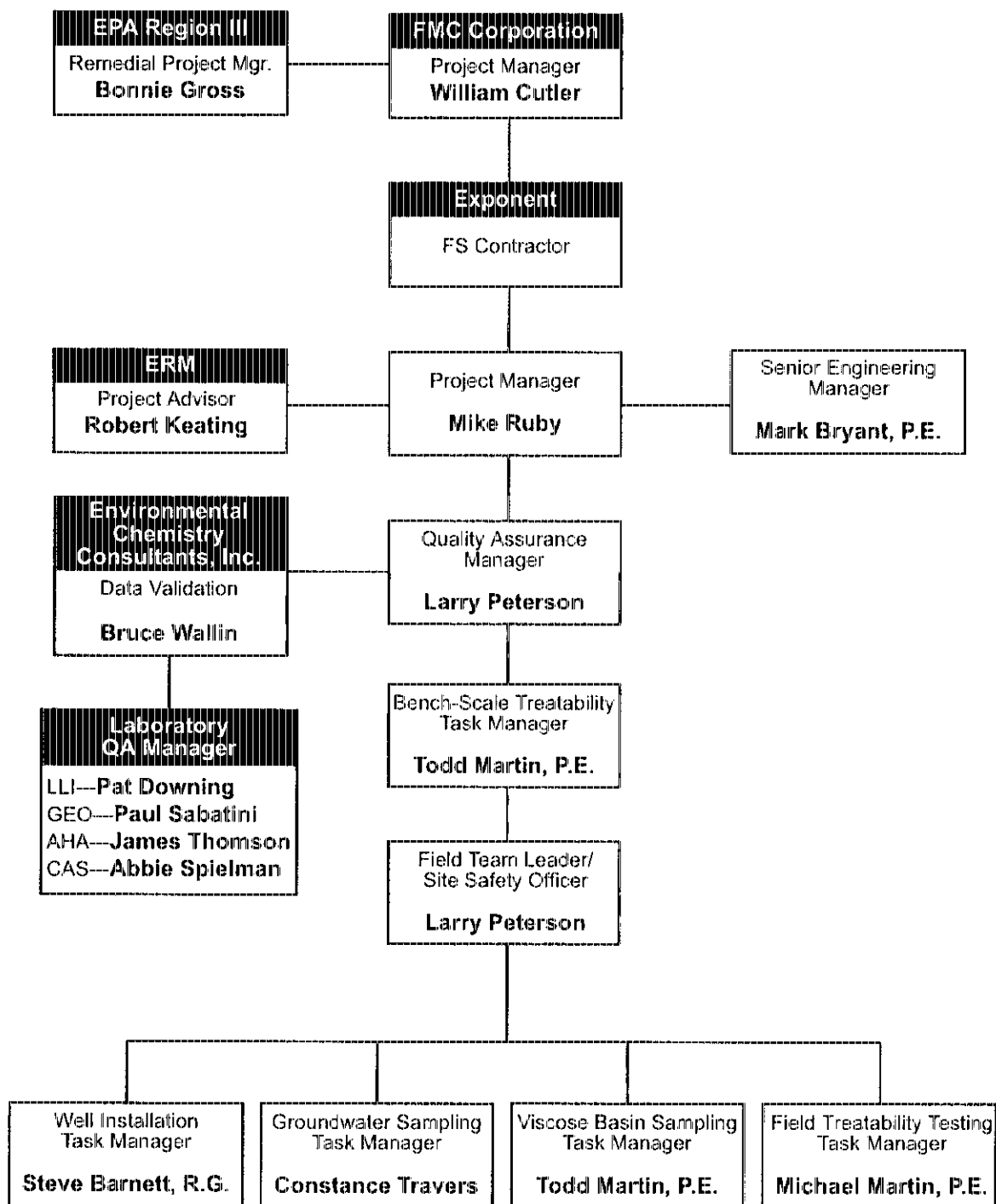


Figure A-9. Project organization for the OU-7 FSAP.

AR301948

Tables

AR301949

Table A-1a. Temporary wellpoint installation summary

Well ID	Unit Monitored	Location	Anticipated		Monitored Interval Depth (ft)	Diameter (in)	Drilling Method	Purpose of Wellpoint
			Total Depth (ft)					
WP01	Viscose	Viscose basin 9	25		15-25	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP02	Viscose	Viscose basin 9	25		15-25	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP03	Viscose	Viscose basin 9	25		15-25	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP04	Viscose	Viscose basin 10	22		12-22	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP05	Viscose	Viscose basin 10	22		12-22	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP06	Viscose	Viscose basin 10	22		12-22	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP07	Viscose	Viscose basin 11	17		7-17	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP08	Viscose	Viscose basin 11	17		7-17	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP09	Viscose	Viscose basin 11	17		7-17	2	Hollow-stem auger on ATV	Monitor basin water levels; basin pore water quality
WP10	Overburden	North of viscose basin 11	25		15-25	2	Hollow-stem auger on ATV	Monitor water levels in overburden near viscose basins
WP11	Overburden	East of viscose basin 11	25		15-25	2	Hollow-stem auger on ATV	Monitor water levels in overburden near viscose basins
WP12	Overburden	East of viscose basin 10	25		15-25	2	Hollow-stem auger on ATV	Monitor water levels in overburden near viscose basins
WP13	Overburden	South of viscose basin 10	25		15-25	2	Hollow-stem auger on ATV	Monitor water levels in overburden near viscose basins
WP14	Overburden	Between viscose basins 9, 10, 11	25		15-25	2	Hollow-stem auger on ATV	Monitor water levels in overburden near viscose basins
GP01	Overburden	Downgradient of Plant	25		20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP02	Overburden	Downgradient of Plant	25		20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP03	Overburden	Downgradient of Plant	25		20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant

Table A-1a. (cont.)

Well ID	Unit Monitored	Location	Anticipated		Diameter (in)	Drilling Method	Purpose of Wellpoint
			Total Depth (ft)	Monitored Interval Depth (ft)			
GP04	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP05	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP06	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP07	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP08	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP09	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP10	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP11	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP12	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP13	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant
GP14	Overburden	Downgradient of Plant	25	20-25	1	Geoprobe®	Characterize water quality and water levels down gradient of plant

Notes: Anticipated well depths and monitored intervals may vary based on field conditions.
ATV - all terrain vehicle

AR301951

Table A-1b. Monitoring well installation summary

Well ID	Unit Monitored	Location	Anticipated Total Depth (ft)	Monitored Interval Depth (ft)	Diameter (inches)	Preferred Drilling Method	Purpose of Monitoring Well
001	Overburden	Near well cluster 101/201/301	25	15-25	2	Hollow stem auger or air rotary	Background overburden water quality
002	Overburden	Near well cluster 102/202/302	25	15-25	2	Hollow stem auger or air rotary	Background overburden water quality
128	Shallow bedrock	West of central portion of plant area	45	35-45	4	Air rotary/downhole air hammer	Water quality downgradient of plant area
129	Shallow bedrock	Southwest of plant area	45	35-45	4	Air rotary/downhole air hammer	Water quality downstrike and downgradient of plant area
130	Shallow bedrock	West of northern portion of plant area	45	35-45	4	Air rotary/downhole air hammer	Water quality downstrike and downgradient of plant area
131	Shallow bedrock	Southwest of boneyard	45	35-45	4	Air rotary/downhole air hammer	Water quality downstrike and downgradient of plant area / boneyard
132	Shallow bedrock	Downstrike of viscose basins 1-8 and new landfill, upstrike of viscose basins 9-11	45	35-45	4	Air rotary/downhole air hammer	Water quality downstrike and downgradient of viscose basins 1-8 / upstrike of viscose basins 9-11
232	Intermediate bedrock	Downstrike of viscose basins 1-8 and new landfill, upstrike of	140	120-140	4	Air rotary/downhole air hammer	Water quality downstrike and downgradient of viscose basins 1-8 / upstrike of viscose basins 9-11
343	Deep bedrock	Southwest of wells 115/215/315 (target elevation = 290-300 ft msl)	330	TBDF	4	Air rotary/downhole air hammer	Downstrike extent of leading edge of dense carbon disulfide plume, installation contingent on Phase I sample results

Notes: Anticipated well depths and monitored intervals may vary based on field conditions.
TBDF - to be determined in the field based on monitoring during drilling for indicators of plume (specific conductivity)

AR301952

Table A-2. Well construction details, Avtex site, Front Royal, Virginia

Well ID	Date Installed	Unit	Northing	Easting	Ground Surface Elevation (ft amsl)	Monitoring Point Elevation (ft amsl)	Diameter (in)	Total Depth of Well BGS (ft)	Bedrock Depth Below GSE (ft)	Bedrock Elevation (ft amsl)	Casing Depth (ft)	Screen Length (ft)	Monitoring Depth (ft bgs)		Depth to Water 04/26/94 (ft)
													Top of Screen or Open Hole if not Screened	Bottom of Screen or Open Hole if not Screened	
004	9/7/89	Overburden	7021555.189	11562899.77	479.32	480.68	2	13				5	8	13	9.29
005	9/15/89	Overburden	7018960.846	11563643.45	500.39	502.88	2	31.5				10	21.5	31.5	20.80
008	9/20/89	Overburden	7018410.492	11565809.12	524.43	525.26	2	14.5				5	9.5	14.5	8.97
009	9/13/89	Overburden	7016769.055	11565226.54	514.57	516.42	2	45.5				5	40.5	45.5	43.15
010	9/8/89	Overburden	7017467.856	11564697.47	478.78	480.88	2	11.7				5	6.7	11.7	8.11
011	9/9/89	Overburden	7017838.342	11564568.86	515.03	517.2	2	46.5				5	41.5	46.5	37.92
012	9/13/89	Overburden	7018658.256	11564742.54	510.36	512.1	2	36.5				10	26.5	36.5	10.97
013	9/14/89	Overburden	7019150.1	11564560.67	508.75	511.58	2	35.2				10	25.2	35.2	14.39
014	9/14/89	Overburden	7019529.82	11564492.35	504.9	506.99	2	19.5				10	9.5	19.5	3.33
017	11/3/89	Overburden	7021204.716	11562879.19	480	482.27	2	14.5				5	9.5	14.5	11.65
021	9/12/89	Overburden	7018149.907	11564255.25	477.87	479.96	2	9.1	9	468.87		5	4.1	9.1	9.22
022	9/12/89	Overburden	7018677.577	11563936.85	478.01	478.25	2	7.1	8	468.01		5	2.1	7.1	7.23
023	9/20/89	Overburden	7019272.002	11563495.88	472.71	474.89	2	5.5	6	466.71		3	2.5	5.5	4.30
024	9/16/89	Overburden	7019843.287	11563157.01	477.11	478.89	2	9	10.5	466.61		5	4	9	8.59
025	9/16/89	Overburden	7020322.95	11562944.32	472.27	474.57	2	5.5	5.3	466.97		2	3.5	5.5	4.82
026	9/16/89	Overburden	7020627.791	11562902.19	472.74	474.3	2	5.2	5.5	467.24		2	3.2	5.2	4.94
091		Deep BR	7018925.014	11562858.69	610.73	611.46	6	275						275	67.69
101	10/19/89	Shallow BR	7022129.775	11566965.83	549.76	551.82	4	45	27	522.76	25	25	25	47	6.64
102	11/2/89	Shallow BR	7019323.745	11566828.18	561.29	563.07	4	45	25.5	535.79	25	25	25	45	6.82
103	10/31/89	Shallow BR	7020219.504	11565232.33	522.92	525.08	4	45	13	509.92	25	25	25	41	4.42
104	11/14/89	Shallow BR	7021568.701	11562896.71	478.76	481.13	4	45	13.5	465.82	25	25	25	45	11.36
105	12/2/89	Shallow BR	7018997.469	11583901.45	495.7	498.59	4	61	34.1	466.29	41		41	52	24.36
106	10/26/89	Shallow BR	7021906.145	11566694.58	541.04	543.07	4	39	14	527.04	18		18	39	4.54
108	10/31/89	Shallow BR	7018412.52	11565796.32	523.72	525.92	4	43	18	505.72	22		22	43	9.14
109	10/27/89	Shallow BR	7016755.115	11565236.11	515.02	518.66	4	82	48	467.02	52		52	85	39.43
110	10/27/89	Shallow BR	7017469.494	11564676.07	477.72	479.97	4	39	14	463.72	18		18	39	7.69
111	10/13/89	Shallow BR	7017860.808	11564556.66	515	516.45	4	73	48	467	52		52	77	41.97
112	10/13/89	Shallow BR	7018671.406	11564742.5	510.26	511.58	4	63	39	471.26	43		43	63	9.21

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Table A-2. (cont.)

Well ID	Date Installed	Unit Monitored	Northing	Easting	Ground Surface Elevation (ft amsl)	Monitoring Point Elevation (ft amsl)	Diameter (in)	Total Depth of Well BGS (ft)	Bedrock Depth (ft)	Bedrock Elevation (ft amsl)	Casing Depth (ft)	Screen Length (ft)	Monitoring Depth		Water Level 04/28/94 (ft)
													Top of Screen or Open Hole if not Screened	Bottom of Screen or Open Hole if not Screened	
113	10/13/89	Shallow BR	7019142.749	11564562.97	509.18	511	4	63	39	470.18	43	43	63	63	11.59
114	10/12/89	Shallow BR	7019521.626	11564471.88	506.28	506.85	4	55	30	476.28	35	35	55	55	9.52
115	12/12/89	Shallow BR	7018223.853	11563306.57	498.12	500.9	4	40	15	483.12	17	17	43	43	19.19
116	12/5/89	Shallow BR	7020146.983	11564266.25	525.65	528.24	4	75	55	470.67	55	55	75	75	34.19
117	10/28/89	Shallow BR	7021214.757	11562876.36	480.5	482.21	4	43	18	462.5	22	22	43	43	11.68
118	12/1/89	Shallow BR	7022154.409	11564897.52	529.36	530.72	4	48	23	506.36	27	27	48	48	10.33
119	12/1/89	Shallow BR	7022305.402	11564345.22	505.65	509.25	4	35	10	495.65	14.5	15	35	35	5.15
120	12/1/89	Shallow BR	7022311.436	11564039.34	504.09	506.19	4	40	15	489.09	19.2	19	38	38	3.88
133		Intermed. BR	7019911.551	11562489.95	499.89	501.09	6						92	92	17.04
136		Intermed. BR	7018455.465	11563316.13	494.3	496.05	6	205					200	200	10.01
137		Shallow BR	7018320.242	11563697.2	488.89	489.29	6	65					72	72	16.87
141		Intermed. BR	7018967.403	11563098.53	490.6	491.5	6	94					79	79	19.33
162		Shallow BR	7017922.998	11563940.55	489.39	490.04	6	62					65	65	17.27
177		Shallow BR	7018246.775	11563338.1	499.01	499.41	6	65				25	69	69	24.07
178		Intermed. BR	7021100.84	11562441.05	491.7	492.6	6	120					113	113	21.30
179		Intermed. BR	7020617.393	11562497.7	491.86	492.88	6	110					113	113	19.83
181		Intermed. BR	7018713.41	11563398.96	491.16	491.66	6	174					173	173	18.16
185		Intermed. BR	7018155.503	11563692.34	491.99	492.9	6	72					72	72	17.98
201	10/18/89	Intermed. BR	7022136.589	11566971.24	550.27	552.39	4	180	27	522.76	160	160	165	165	12.22
202	11/3/89	Intermed. BR	7019325.826	11566812.84	561.12	563.91	4	180	25.5	535.79	160	160	186	186	13.27
203	10/28/89	Intermed. BR	7020210.268	11565235.36	523	524.23	4	180	13	509.92	160	160	188	188	4.23
204	11/14/89	Intermed. BR	7021592.037	11562893.84	479.52	481.73	4	180	13.5	465.82	160	160	186	186	11.09
205	12/14/89	Intermed. BR	7018994.959	11563887.69	498.25	500.31	4	180	34.1	466.29	160	160	187	187	22.78
210	10/25/89	Intermed. BR	7017477.817	11564691.74	478.47	480.65	4	100	14	463.72	78	78	100	100	7.81
215	12/13/89	Intermed. BR	7018223	11563297.87	498.1	500.83	4	180	15	483.12	160	160	183	183	24.55
216	12/15/89	Intermed. BR	7020143.011	11564259.16	525.67	528.67	4	180	55	470.67	160	160	180	180	57.21

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Table A-2. (cont.)

Well ID	Date Installed	Unit Monitored	Northing	Easting	Ground Surface Elevation (ft amsl)	Monitoring Point Elevation (ft amsl)	Diameter (in)	Total Depth of Well BGS (ft)	Bedrock Depth Below GSE (ft)	Bedrock Elevation (ft amsl)	Casing Depth (ft)	Monitoring Depth			04/28/94
												Screen Length (ft)	Top of Screen or Open Hole if not Screened	Bottom of Screen or Open Hole if not Screened	
301	10/31/89	Deep BR	7022120.358	11566979.63	549.63	551.74	4	250	27	522.76	230	230	250	250	12.57
302	10/24/89	Deep BR	7019327.547	11566839.23	560.87	563.22	4	250	25.5	535.79	230	230	250	250	27.68
303	10/13/89	Deep BR	7020200.549	11565234.96	523.04	525.46	4	308	13	509.92	280	280	307	307	Dry
304	11/7/89	Deep BR	7021576.301	11562895.47	479.09	481.49	4	300	13.5	465.82	280	280	303	303	54.74
305	11/15/89	Deep BR	7018978.444	11563860.51	499	501.63	4	300	34.1	466.29	280	280	300	300	59.11
315	12/13/89	Deep BR	7018222.312	11563288.76	497.83	500.88	4	250	15	483.12	230	230	251	251	250.45
316	12/6/89	Deep BR	7020140.566	11564254.59	525.6	528.57	4	250	55	470.67	230	230	250	250	125.02
GM01A	11/15/79	Shallow BR	7019555.024	11563430.21	497.25	500.91	4	100	37	460.25	44	44	75	75	26.68
GM01B	11/17/79	Intermed. BR	7019552.018	11563423.79	497.53	497.59	4	150	30	467.53	100	100	104	104	25.23
GM02A	11/29/79	Intermed. BR	7018542.341	11563466.93	489.85	489.85	4	100	20	469.85	28	28	101	101	14.71
GM02B	11/30/79	Intermed. BR	7018523.049	11563435.04	490.45	490.45	4	175	20	470.45	100	100	163	163	15.65
GM03	12/12/79	Intermed. BR	7021933.364	11562899.39	484.91	486.42	4	125	19	465.91	22	22	149	149	14.47
GM04	12/21/79	Intermed. BR	7022138.781	11563542.96	489.16	489.78	4	125	16	473.16	21	21	121	121	6.55
GM05	12/16/79	Intermed. BR	7020535.923	11563000.73	496.05	499.38	4	125	32	464.05	42	42	126	126	26.90
GM06	12/15/79	Intermed. BR	7019018.212	11563782.69	497.8	497.54	4	152	33	464.8	43	43	149	149	19.75
GM07	12/15/79	Intermed. BR	7018021.957	11564555.02	484.21	485.11	4	125	17	467.21	27	27	115	115	9.60
GM08	12/19/79	Intermed. BR	7020170.485	11564283.42	524.94	526.57	4	132	40	484.94	50	50	132	132	30.29
GM09	12/19/79	Intermed. BR	7018729.734	11563993.34	505.06	504.8	4	152	40	465.06	50	50	149	149	29.38
MW01		Shallow BR	7022140.792	11566977.98	550.61	552.68	4	35	26.5	524.11	26.5	27	35	35	9.33 ^a
MW02	7/1/77	Overburden	7020585.877	11564341.17	523.65	526.44	2	28			5	23.5	26	26	21.78
MW03	7/1/77	Shallow BR	7020567.502	11564345.81	523.91	526.25	4	40	30	493.91	32.5	33	44	44	26.43
MW04	7/1/77	Shallow BR	7020509.138	11563014.86	496.14	498.73	4	40	31	465.14	33.5	34	36	36	25.77
MW05	7/1/77	Shallow BR	7022183.507	11563537.8	489.7	493.18	4	33	22	467.7	22	22	30	30	9.09
MW06	7/1/77	Shallow BR	7018957.783	11563882.3	500.21	502.42	4	40	33.5	466.71	33.5	34	39	39	22.33
MW07		Overburden	7021162.755	11564449.19	530.52	532.24	4	40			5	35	40	40	21.16
MW08		Overburden	7021018.593	11564499.05	528.28	529.14	4	40			5	35	40	40	18.36
MW09	7/21/83	Overburden	7020451.976	11564068.39	521.57	524.65	4	42			15	27	42	42	17.09
MW10	7/22/83	Overburden	7019923.477	11564281.16	525.29	527.39	4	53			15	38.5	53.5	53.5	34.87

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Table A-2. (cont.)

Well ID	Date Installed	Unit Monitored	Northing	Easting	Ground Surface Elevation (ft amsl)	Monitoring Point Elevation (ft amsl)	Diameter (in)	Total Depth of Well BGS (ft)	Bedrock Depth Below GSE (ft)	Bedrock Elevation (ft amsl)	Casing Depth (ft)	Screen Length (ft)	Monitoring Depth	
													Top of Screen or Open Hole if not Screened	Bottom of Screen Water Level or Open Hole if not Screened
MW11	7/27/83	Overburden	7021456.713	11564058.62	524.32	525.83	4	30				10	20	30
MW12	7/28/83	Overburden	7021060.837	11564041.66	504.65	506.97	4	13				5	8	13
PW0	10/25/80	Intermed. BR	7018547.82	11564129.53	505.2	505.92	6	158	23	482.2	33		33	158
PW01	12/27/79	Intermed. BR	7018743.288	11563983.1	504.83	504.69	6	162	37	467.93	50		50	149
PW02	1/3/80	Intermed. BR	7019007.7	11563792.74	497.88	497.6	6	150	31	466.88	43		43	150
PW03	10/31/80	Intermed. BR	7019273.112	11563574.66	498.04	497.78	6	157	31	467.04	40		40	164
PW04	11/3/80	Intermed. BR	7020043.744	11563124.53	496.02	496.12	6	158	31	465.02	43		43	158
PZ01	6/21/83	Shallow BR	7020811.904	11562886.11	475.03	478.14	4	35	11	464.03	18		18	35
PZ02	6/22/83	Shallow BR	7020804.583	11562884.79	475.18	477.54	4	16	9	466.18	13.5		14	16
PZ03	6/22/83	Shallow BR	7020350.496	11562938.12	473.05	474.96	4	18	7	466.05	13		13	19
PZ04	6/24/80	Shallow BR	7019977.46	11563070.25	477.73	480.06	4	31	10.5	467.23	17		17	31
PZ05	6/29/83	Shallow BR	7019571.743	11563310.3	475.45	478.24	4	25	7.5	467.95	13		13	25
PZ06	6/29/83	Shallow BR	7019121.471	11563627.02	476.13	478.63	4	23	8	468.13	12		12	23
PZ07	7/1/83	Shallow BR	7018478.216	11564090.48	477.14	479.65	4	23	10	467.14	13		13	23
PZ08	7/6/83	Shallow BR	7018827.778	11563845.75	476.65	479.27	4	18	8	468.65	13		13	18
PZ09	7/6/83	Shallow BR	7018622.732	11563842.42	475.87	478.72	4	28	8	467.87	23		23	28
PZ10	7/29/83	Shallow BR	7018152.346	11564255.16	477.63	479.93	4	18	9	468.63	13		13	13
PZ11	7/29/83	Shallow BR	7018822.65	11563847.9	476.71	479.5	4	80	8	468.71	50		50	78

Note: amsl - above mean sea level

BGS - below ground surface

BR - bedrock

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Table A-3. Well and wellpoints sampling and analysis plan

Well ID	Proposed or Existing	On-site/ Off-site	TCL VOCs	TCL SVOCs	TAL		TAL		PCBs	Pesticides	Ammonia Nitrogen	Field Measurements	Arsenic Speciation	Conventional	Density	COD	Lab
					Inorganics (Unfiltered)	Inorganics (Filtered)	Inorganics (Filtered)	Inorganics (Filtered)									
Overburden																	
GP01	Proposed	On-site	X	X	X			X		X	X	X					
GP02	Proposed	On-site	X	X	X			X		X	X	X					
GP03	Proposed	On-site	X	X	X			X		X	X	X					
GP04	Proposed	On-site	X	X	X			X		X	X	X					
GP05	Proposed	On-site	X	X	X			X		X	X	X					
GP06	Proposed	On-site	X	X	X			X		X	X	X					
GP07	Proposed	On-site	X	X	X			X		X	X	X					
GP08	Proposed	On-site	X	X	X			X		X	X	X					
GP09	Proposed	On-site	X	X	X			X		X	X	X					
GP10	Proposed	On-site	X	X	X			X		X	X	X					
GP11	Proposed	On-site	X	X	X			X		X	X	X					
GP12	Proposed	On-site	X	X	X			X		X	X	X					
GP13	Proposed	On-site	X	X	X			X		X	X	X					
GP14	Proposed	On-site	X	X	X			X		X	X	X					
001	Proposed	On-site	X	X	X			X	X	X	X	X					
002	Proposed	On-site	X	X	X			X	X	X	X	X					
004	Existing	On-site	X	X	X			X		X	X	X					
017	Existing	On-site	X	X	X			X		X	X	X					
026	Existing	On-site	X	X	X			X		X	X	X					
MW07	Existing	On-site	X	X	X			X		X	X	X					
MW08	Existing	On-site	X	X	X			X		X	X	X					
MW11	Existing	On-site	X	X	X			X		X	X	X					
MW12	Existing	On-site	X	X	X			X		X	X	X					
MW02	Existing	On-site	X	X	X			X		X	X	X					
MW09	Existing	On-site	X	X	X			X		X	X	X		X		X	
MW10	Existing	On-site	X	X	X			X		X	X	X					
005	Existing	On-site			X			X		X	X	X					
009	Existing	On-site			X			X		X	X	X					
011	Existing	On-site			X			X		X	X	X					
014	Existing	On-site			X			X		X	X	X					
021	Existing	On-site			X			X		X	X	X					
022	Existing	On-site			X			X		X	X	X					
024	Existing	On-site			X			X		X	X	X					

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Table A-3. (cont.)

Well ID	Proposed or Existing	On-site/ Off-site	TCL VOCs	TCL SVOCs	TAL		PCBs	Pesticides	Ammonia Nitrogen	Field Measurements	Arsenic Speciation	Conventional Density	COD	Lab
					Inorganics (Unfiltered)	Inorganics (Filtered)								
Shallow bedrock														
101	Existing	On-site	X	X	X		X	X	X	X		X		
102	Existing	On-site	X	X	X		X	X	X	X	X			
103	Existing	On-site	X	X	X		X	X	X	X				
104	Existing	On-site	X	X	X				X	X				
115	Existing	Off-site	X	X	X				X	X		X		
117	Existing	On-site	X	X	X				X	X				
118	Existing	On-site	X	X	X				X	X				
119	Existing	On-site	X	X	X				X	X		X		
120	Existing	On-site	X	X	X				X	X				
128	Proposed	On-site	X	X	X		X	X	X	X				
129	Proposed	On-site	X	X	X		X	X	X	X				
130	Proposed	On-site	X	X	X		X	X	X	X		X		
131	Proposed	On-site	X	X	X		X	X	X	X				
137	Existing	Off-site	X	X	X				X	X				
162	Existing	Off-site	X	X	X				X	X				
177	Existing	Off-site	X	X	X				X	X		X		
MW04	Existing	On-site	X	X	X				X	X				
MW05	Existing	On-site	X	X	X				X	X				
105	Existing	On-site	X	X	X				X	X		X		
111	Existing	On-site	X	X	X				X	X				
112	Existing	On-site	X	X	X				X	X				
114	Existing	On-site	X	X	X				X	X				
116	Existing	On-site	X	X	X				X	X		X		X
132	Proposed	On-site	X	X	X				X	X		X		
GM01A	Existing	On-site	X	X	X				X	X				
MW03	Existing	On-site	X	X	X				X	X		X		
PZ06	Existing	On-site	X	X	X				X	X				
PZ07	Existing	On-site	X	X	X				X	X				
PZ11	Existing	On-site	X	X	X				X	X				

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Table A-3. (cont.)

Well ID	Proposed or Existing	On-site/ Off-site	TCL VOCs	TCL SVOCs	TAL			PCBs	Pesticides	Ammonia		Field Measurements	Arsenic Speciation	Conventional	Density	COD	Lab
					TCL Inorganics (Unfiltered)	TAL Inorganics (Filtered)	TAL			Nitrogen	Nitrogen						
Intermediate bedrock																	
136	Existing	Off-site	X	X	X					X		X					
181	Existing	Off-site	X	X	X					X		X					
185	Existing	Off-site	X	X	X					X		X					
201	Existing	On-site	X	X	X		X	X	X	X		X		X	X		
202	Existing	On-site	X	X	X		X			X		X	X				
203	Existing	On-site	X	X	X		X	X	X	X		X					
215	Existing	Off-site	X	X	X		X			X		X	X	X	X		X
GM02A	Existing	Off-site	X	X	X		X			X		X					
GM02B	Existing	Off-site	X	X	X		X			X		X					
GM04	Existing	On-site	X	X	X		X			X		X					
GM05	Existing	On-site	X	X	X		X			X		X					
205	Existing	On-site	X	X	X		X			X		X	X	X	X		X
210	Existing	On-site	X	X	X		X			X		X					
216	Existing	On-site	X	X	X		X			X		X					
232	Proposed	On-site	X	X	X		X			X		X		X	X		
GM07	Existing	On-site	X	X	X		X			X		X					
GM08	Existing	On-site	X	X	X		X			X		X					
GM09	Existing	On-site	X	X	X		X			X		X					
PW0	Existing	On-site	X	X	X		X			X		X					
PW02	Existing	On-site	X	X	X		X			X		X					
PW03	Existing	On-site	X	X	X		X			X		X					
Deep bedrock																	
301	Existing	On-site	X	X	X		X	X	X	X		X		X	X		
302	Existing	On-site	X	X	X		X	X	X	X		X	X				
303	Existing	On-site	X	X	X		X	X	X	X		X					
315	Existing	Off-site	X	X	X		X			X		X		X	X		
343	Proposed	Off-site	X	X	X		X			X		X	X	X	X		
305	Existing	On-site	X	X	X		X			X		X	X	X	X		
316	Existing	On-site	X	X	X		X			X		X	X	X	X		

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Table A-3. (cont.)

Well ID	Proposed or Existing	On-site/ Off-site	TCL VOCs	TCL SVOCs	TAL		PCBs	Pesticides	Ammonia Nitrogen	Field Measurements	Arsenic Speciation	Conventional	Density	COD	Lab
					Inorganics (Unfiltered)	Inorganics (Filtered)									
Viscose basin															
WP01	Proposed	On-site	X	X	X				X	X	X	X	X	X	X
WP02	Proposed	On-site	X	X	X				X	X		X	X	X	
WP03	Proposed	On-site	X	X	X				X	X		X	X	X	
WP04	Proposed	On-site	X	X	X				X	X	X	X	X	X	X
WP05	Proposed	On-site	X	X	X				X	X		X	X	X	
WP06	Proposed	On-site	X	X	X				X	X		X	X	X	
WP07	Proposed	On-site	X	X	X				X	X	X	X	X	X	X
WP08	Proposed	On-site	X	X	X				X	X		X	X	X	
WP09	Proposed	On-site	X	X	X				X	X		X	X	X	

Note: Bolded well ids indicate that the well is part of the OU-10 Workplan.

Parameter groups are as follows:

As speciation	arsenic speciation [As(III) / As (V)]
COD	chemical oxygen demand
Conventional	alkalinity, chloride, sulfate, silica, total dissolved solids
Field measurements	pH, temperature, specific conductance, dissolved oxygen, Eh, turbidity, iron speciation
Lab	samples collected for lab testing of carbon disulfide hydrolysis
PCBs	polychlorinated biphenyls
Pesticides	organochlorinated pesticides
TAL inorganics	target analyte list inorganics (EPA 1996), includes chromium speciation [Cr(VIII)/Cr(VI)]
TCL SVOCs	target compound list SVOCs (EPA 1994)
TCL VOCs	target compound list VOCs (EPA 1994)

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Table A-4. Sample containers, preservation, and handling procedures

Analyte	Approximate Laboratory Subsample	Container	Preservation and Handling	Maximum Holding Times (days)
Water				
Organic Compounds				
TCL SVOCs	1,000 mL	2 x 1-L amber glass jar; Teflon [®] -lined lid	Keep in dark; cool (4°C)	7/40
TCL VOCs	40 mL	3 x 40-mL VOA vial; Teflon [®] -lined lid	HCl to pH <2; keep in dark; cool (4°C)	14
Organochlorine pesticides	1,000 mL	1-L amber glass jar; Teflon [®] -lined lid	Keep cool (4°C)	7/40
PCBs	1,000 mL	1-L amber glass jar; Teflon [®] -lined lid	Keep in dark; cool (4°C)	7/40
TAL Inorganics				
Metals	100 mL	500-mL HDPE bottle; Teflon [®] -lined lid	HNO ₃ to pH <2; cool (4°C)	180 ^a
Cyanide	100 mL	1-L HDPE bottle; Teflon [®] -lined lid	NaOH to pH >12; cool (4°C)	14
Metals				
Arsenic (III/IV) speciation	60 mL	125 mL HDPE or glass bottle; Teflon [®] -lined lid	HCl to pH <2; zero headspace; cool (4°C)	28
Hexavalent chrome	200 mL	500-mL HDPE bottle; Teflon [®] -lined lid	NaOH; cool (4°C) (by EPA Method 1669)	30
Physical Properties				
Specific gravity (density)	100 mL	250-mL HDPE bottle	Keep cool (4°C)	NA
Total dissolved solids	250 mL	1-L HDPE bottle	Keep cool (4°C)	7
Conventional Analytes				
Total alkalinity	100 mL	250-mL HDPE bottle	Keep in dark; cool (4°C)	14
Ammonia nitrogen	400 mL	1-L HDPE bottle	H ₂ SO ₄ to pH<2; cool (4°C)	28
Chloride (Total)	100 mL	1-L HDPE bottle	Keep in dark; cool (4°C)	28
COD	100 mL	100 mL glass jar; Teflon [®] -lined lid	H ₂ SO ₄ to pH<2; cool (4°C)	ASAP
Silica	50 mL	250-mL HDPE bottle	Keep cool (4°C)	28
Sulfate	50 mL	1-L HDPE bottle	Keep in dark; cool (4°C)	28
Laboratory Testing				
CS ₂ hydrolysis testing (VOC)	40 mL	3 x 40-mL VOA vials; Teflon [®] -lined lid	Keep in dark; cool	NA
CS ₂ hydrolysis testing (inorganics)	100 mL	500-mL amber glass jar; Septum lid, Teflon [®] -lined lid	Keep in dark; cool	NA
Electrical resistance heating testing	250 mL	1-L HDPE bottle	Keep in dark; cool (4°C)	NA
Solids				
Organic Compounds				
TCL SVOCs	100 g	16 oz. glass jar with Teflon [®] -lined lid	Keep in dark; cool (4°C)	14/40
TCL VOCs	5 g	3.5-g EnCore™ samplers	Keep in dark; cool (4°C)	2

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Table A-4. (cont.)

Analyte	Approximate Laboratory Subsample	Container	Preservation and Handling	Maximum Holding Times (days)
Solids (cont.)				
TAL Inorganics				
Metals	100 g	16 oz. glass jar with Teflon®-lined lid	Keep in dark; cool (4°C)	180
Cyanide	20 g	16 oz. glass jar with Teflon®-lined lid	Keep in dark; cool (4°C)	14
Conventional Analytes				
Ammonia nitrogen	100 g	16 oz. glass jar with Teflon®-lined lid	Keep in dark; cool (4°C)	28
Total chloride	10 g	16 oz. glass jar with Teflon®-lined lid	Keep in dark; cool (4°C)	28
pH	50 g	16 oz. glass jar with Teflon®-lined lid	Keep in dark; cool (4°C)	ASAP
Silica	100 g	16 oz. glass jar with Teflon®-lined lid	Keep in dark; cool (4°C)	28
Sulfate	10 g	16 oz. glass jar with Teflon®-lined lid	Keep in dark; cool (4°C)	28
Moisture content	50 g	16 oz. glass jar with Teflon®-lined lid	Keep in dark; cool (4°C)	28
Other Parameters				
Hydrologic parameters	TBD	2 in. diameter, 12 in. long stainless steel sleeve	Keep in dark; cool (4°C)	NA
Hydraulic conductivity	TBD	2 in. diameter, 12 in. long stainless steel sleeve	Keep in dark; cool (4°C)	NA
Consolidation tests	3 in. x 6 in. core	3 in. diameter, 24 in. long Shelby tube	Keep in dark; cool (4°C)	NA
Free and bound CS ₂	4 g	2 in. diameter, 6 in. long stainless steel sleeve	Keep in dark; cool (4°C)	NA
Hydroxide liberation tests	5 g	2 in. diameter, 6 in. long stainless steel sleeve	Keep in dark; cool (4°C)	NA
ERH tests	2 in. x 12 in. core	2 in. diameter, 12 in. long stainless steel sleeve	Keep in dark; cool (4°C)	NA
Laboratory treatability tests	9 gal	9 x 3.5 gal. HDPE bucket	Keep in dark; cool (4°C)	NA

Note: ASAP - as soon as possible
 COD - chemical oxygen demand
 CS₂ - carbon disulfide
 ERH - electrical resistance heating
 HDPE - high-density polyethylene
 NA - not applicable
 PCB - polychlorinated biphenyl
 SVOC - semivolatile organic compound
 TAL - target analyte list
 TBD - to be determined
 TCL - CLP target compound list
 VOC - volatile organic compound

^a Mercury holding time is 28 days.

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Table A-5. Groundwater sample collection sequence for wells and wellpoints at the Avtex site

Well Type:	Overburden wells and viscose basin wellpoints^a	Bedrock wells	Geoprobe[®] wellpoints, overburden wells, and viscose basin wellpoints^c
Purging Equipment:	Teflon [®] -lined bladder pump with Teflon [®] -lined tubing	Submersible pump with Teflon [®] -lined tubing	Peristaltic pump with Teflon [®] -lined tubing
Sampling Equipment:	Teflon [®] -lined bladder pump with Teflon [®] -lined tubing	Submersible pump with Teflon [®] -lined tubing	Peristaltic pump with Teflon [®] -lined tubing / Teflon [®] bailer (for VOCs only)
Sample Collection Sequence:	<ol style="list-style-type: none"> 1. TCL VOCs 2. Carbon disulfide hydrolysis (VOA vials) 3. Carbon disulfide hydrolysis (500-mL bottle) 4. TCL SVOCs 5. Cr (VI) speciation 6. As speciation 7. TAL inorganics (unfiltered) 8. TAL Inorganics (filtered; Overburden wells only)^b 9. Cyanide 10. Anions, TDS, density 11. Ammonia nitrogen 12. PCBs / organochlorine pesticides 13. ERH samples 	<ol style="list-style-type: none"> 1. TCL VOCs 2. Carbon disulfide hydrolysis (VOA vials) 3. Carbon disulfide hydrolysis (500-mL bottle) 4. TCL SVOCs 5. Cr (VI) speciation 6. As speciation 7. TAL inorganics 8. Cyanide 9. Anions, TDS, density 10. Ammonia nitrogen 11. PCBs / organochlorine pesticides 12. ERH samples 	<ol style="list-style-type: none"> 1. TCL SVOCs 2. Cr (VI) speciation 3. As speciation 4. TAL inorganics (unfiltered) 5. TAL inorganics (filtered; Overburden wells only)^b 6. Cyanide 7. Anions, TDS, density 8. Ammonia nitrogen 9. PCBs / organochlorine pesticides 10. ERH samples 11. TCL VOCs

Note: cv - casing volume

^a With more than 5 feet of water above the mid-point of the saturated screened interval.

^b Sample will be collected in a new, non-preserved 1-L HDPE bottle. Water from this bottle will be field-filtered using a peristaltic pump after all of the samples have been collected.

^c With less than 5 feet of water above the mid-point of the saturated screened interval.

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Table A-6. Waste viscose and soil sample collection summary for viscose basin boreholes

Test Type	Sampling Method ^a	Sample Dimensions	Number of Basins	Locations per Basin	Sample Depths						Total Samples	Lab ^b
					Unsaturated Zone			Saturated Zone				
					0–12"	12–24"	Above	Below	Base of	Top of		
						Water Table	Viscose	Overburden				
Material/Geotechnical Properties												
Waste viscose hydrologic parameters ^c	SS Liner	2-in ID, 12-in long	3	2	x	x					12	GEO
Overburden vertical hydraulic conductivity	SS Liner	2-in ID, 12-in long	3	1						x	3	GEO
Consolidation/shear tests	Shelby Tube	3-in ID, 24-in long	3	1	x	x					9	GEO
Chemical Source Characterization												
Free and bound CS ₂ analysis	SS Liner	2-in ID, 6-in long	3	1		x		x			9	CAS
Hydroxide liberation tests	SS Liner	2-in ID, 6-in long	3	1		x		x			9	EBL
Chemical analysis ^d	Splitspoon	2-in ID, 12-in long	3	2		x		x			18 + 1 dup ^e	CAS
Laboratory Treatability Testing												
Chemical oxidation tests	Composite	NA	3	3							9 ^f	EBL
Vermiculture treatment tests	Composite	NA	3	3							9 ^f	SWI
Direct electrical resistance heating tests	SS Liner	2-in ID, 12-in long	3	1	x		x				9	AHA
Handling improvement tests	Composite	NA	3	3							9 ^f	EBL

Note: CS₂ - carbon disulfide
ID - inner diameter
NA - not applicable
SS - stainless steel

^a All SS liners and shelby tube samples will be sealed with end caps and Teflon tape.

^b Lab abbreviations are as follows:

AHA Applied Hydrology Associates, Inc.
CAS Columbia Analytical Services
EBL Exponent Boulder Lab
GEO GeoSyntec Consultants
SWI Smartworm, Inc.

^c Viscose hydrologic parameters include field capacity, wilting point, vertical hydraulic conductivity, porosity, moisture content, and bulk density.

^d Includes quantification of carbon disulfide, TAL inorganics, TCL VOCs, TCL SVOCs, chloride, silica, sulfate, paste pH, COD, and percent solids

^e At one select location, an additional borehole, immediately adjacent to the initial borehole, will be installed to collect a duplicate sample for chemical analysis.

^f Material collected from across the thickness of the waste viscose (excluding the crust layer).

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Table A-7. Laboratory shipping addresses

Contact Information	
Exponent Testing Laboratory Attention: Larry Peterson 4940 Pearl East Circle, Suite 300 Boulder, CO 80301 (303) 444-7270	University of Colorado Attention: John Drexler Benson Earth Sciences Building 2200 Colorado Avenue Boulder, CO 80309 (303) 492-5251
McMillian-McGee Attention: Bruce McGee Star Building 3504 64th Avenue, S.E. Calgary, Alberta, Canada T2C 1P4 (403) 686-7186	GeoSyntec Consultants Attention: Paul Sabatini 1100 Lake Hearn Drive, Suite 200 Atlanta, GA 30342 (404) 705-9500
Smartworm Technology, Inc. Reg Renaud 28281 Silverado Canyon Road P.O. Box 792 Silverado, CA 92676-0792 (714) 583-9676	Columbia Analytical Services Attention: Joe Wiegel 1317 South 13th Avenue P.O. Box 479 Kelso, WA 98626 1-800-695-7222
Frontier Geosciences Attention: Dirk Wallschlaeger 414 Pontius North Seattle, WA 98109 (206) 622-6960	Lancaster Laboratories, Inc. Attention: Kay Hower 2425 Holland Pike Lancaster, PA 17601 (713) 656-2308 Ext. 1528
RJ Lee Group, Inc. 350 Hochberg Road Monroeville, PA 15146 (724) 325-1776	

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Table A-b. Summary of analytical methods and critical indicators for groundwater and solids

Analysis	Method Reference	Target Analytical Option	Data Validation Level	Matrix	Units	Method Reporting Limits ^a	Bias (percent)	Laboratory			Completeness (%)
								Replicate Precision (RPD)	Sample Precision (RPD)		
Organics											
TCL SVOCs	EPA Method 8270C (prep 3510C/3520C) EPA Method 8270C (prep 3550B/3540C)	IV IV	2 2	Water Solids	µg/L µg/kg	10–100 330–2,000	75–125 75–125	-- --	30 50		90 90
TCL VOCs	EPA Method 8260B (prep 5030B) EPA Method 8260B (prep 5035)	IV IV	2 2	Water Solids	µg/L µg/kg	5–20 ^b 5–20	75–125 75–125	-- --	30 50		90 90
Organochlorine pesticides	EPA Method 8081A (prep 3510C)	IV	2	Water	µg/L	0.01–1	75–125	--	30		90
PCBs	EPA Method 8082 (prep 3510C/3520C)	IV	2	Water	µg/L	0.5	75–125	--	30		90
TAL Inorganics											
Metals (minus As, Hg, Cr & Trace Metals)	EPA Method 6010B (prep 3010A)	IV	2	Water	mg/L	0.01–0.6 ^b	75–125	20	30		90
Metals (minus Hg & Cr)	EPA Method 6010B (prep 3050B)	IV	2	Solids	mg/kg	0.1–100	75–125	30	50		90
Metals (Sb, Cd, Cr, Pb, Se, Ti)	EPA Method 6010B Trace (prep 3010A)	IV	2	Water	mg/L	0.0015–0.02 ^b	75–125	20	30		90
Metals (As)	EPA Method 7060A	IV	2	Water	mg/L	0.010 ^b	75–125	20	30		90
Cyanide	EPA Method 9012A	IV IV	2 2	Water Solids	mg/L mg/kg	0.005 0.5	75–125 75–125	20 30	30 50		90 90
Mercury	EPA Method 7470A EPA Method 7471A (3050B)	IV IV	2 2	Water Solids	mg/L mg/kg	0.0002 ^b 0.1	75–125 75–125	20 30	30 50		90 90
Metals											
Hexavalent chrome	EPA Method 7196A (preserved per EPA 1609)	III	4	Water	mg/L	0.01	75–125	20	30		90
Arsenic III & V	EPA Method 1632A	III	4	Water	µg/L	0.05 (III); 0.1 (V) ^c	75–125	25	30		90
Physical Properties											
Percent solids	EPA Method 160.3 Modified	III	4	Solids	percent	--	--	--	--		--
Total dissolved solids	EPA Method 160.1	III	4	Water	mg/L	30					
Specific gravity (density)	ASTM Method D1429-95	III	4	Water	NA	--	--	--	--		--
Conventional Parameters											
Total alkalinity	EPA Method 310.1	III	4	Water	mg/L	1 ^b	75–125	20	30		90
Ammonia nitrogen	EPA Method 350.2	IV IV	2 2	Water Solids	mg/L mg/kg	1 20	75–125 75–125	20 30	30 50		90 90
Chloride (Total)	EPA Method 300.0	III III	4 4	Water Solids	mg/L mg/kg	2 ^b 20	75–125 75–125	20 30	30 50		90 90
COD	EPA Method 410.4	III	4	Water	mg/L	50	--	--	--		--
pH	EPA Method 9040B EPA Method 9045C	III III	4 4	Water Solids	pH units pH units	-- --	-- --	-- --	-- --		-- --
Silica	EPA Method 370.1	III	4	Water	mg/L	0.1 ^b	75–125	20	30		90
Sulfate	EPA Method 300.0	III III	4 4	Water Solids	mg/L mg/kg	5 ^b 50	75–125 75–125	20 30	30 50		90 90

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Table A-8. (cont.)

Note: " - Not applicable
 COD - chemical oxygen demand
 EPA - U.S. Environmental Protection Agency
 PCB - polychlorinated biphenyl
 RPD - relative percent difference
 SVOC - semivolatile organic compound
 VOC - volatile organic compound

^a Lancaster Laboratory reporting limits unless otherwise noted. Elevated method reporting limits may be reported if dilutions are required. Method reporting limits for individual analytes are provided in Tables A-10, A-11, A-12, A-13, A-14, and A-15.

^b This method reporting limit also applies to Columbia Analytical Services, Inc. (in addition to Lancaster Laboratories).

^c Method reporting limits for Frontier Geosciences, Inc.

^d The method reporting limit for this analyte varies depending on the amount of sample used in analysis.

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Table A-9. Methods for materials/geotechnical properties testing, chemical characterization testing, and laboratory treatability testing

Test Type	Target Analytical Option	Matrix	Data Validation Level	Method	Lab ^a
Materials/Geotechnical Properties					
Field capacity	III	Viscose	4	ASTM D5298	GEO
Wilting point	III	Viscose	4	ASTM D5298	GEO
Vertical hydraulic conductivity	III	Viscose/Overburden	4	ASTM D5084	GEO
Specific gravity (particle density)	III	Viscose	4	ASTM D854	GEO
Porosity	III	Viscose	4	Calculation ^b	GEO
Moisture content	III	Viscose	4	ASTM D2216	GEO
Bulk density	III	Viscose	4	ASTM D2937	GEO
Consolidation tests ^c	III	Viscose	4	ASTM D2435-96	GEO
Vane shear test	III	Viscose	4	ASTM D4648-94	GEO
Chemical Source Characterization					
Free and bound CS ₂ analysis	III	Viscose	4	Attachment 9	CAS
Hydroxide liberation tests	III	Viscose	4	Attachment 10	EBL
Laboratory Treatability Testing					
Chemical oxidation tests	III	Viscose	4	LTAP	EBL
Vermiculture treatment tests	III	Viscose	4	LTAP	EBL
Direct electrical resistance heating tests	III	Viscose	4	Attachment 4	AHA/MC2
Handling improvement tests	III	Viscose	4	LTAP	EBL

Note: With the exception of the consolidation test samples, which will be collected with a 2-ft Shelby Tube, all samples will be collected using 6-in. or 12-in. stainless steel split-spoon sampler liners. All samples will be sealed with plastic end caps and Teflon tape. LTAP - procedures will be developed and presented in a Laboratory Testing and Analysis Plan

^a Lab abbreviations are as follows:

AHA Applied Hydrology Associates, Inc.
CAS Columbia Analytical Services
EBL Exponent Boulder Lab
GEO GeoSyntec Consultants
MC2 McMillian-McGee

^b Porosity= 1-(bulk density/particle density)

^c 3-inch diameter core

Table A-10. Quantitation limits for volatile organic compounds

Analyte	Water MDL ($\mu\text{g/L}$)	Water MRL ($\mu\text{g/L}$)	Soil MDL ($\mu\text{g/kg}$)	Soil MRL ($\mu\text{g/kg}$)
Acetone	6	20	7	20
Benzene	1	5	1	5
Bromodichloromethane	1	5	2	5
Bromoform	1	5	1	5
Bromomethane	3	5	3	5
2-Butanone	3	10	7	10
Carbon disulfide	3	5	3	5
Carbon tetrachloride	1	5	1	5
Chlorobenzene	1	5	1	5
Chloroethane	3	5	3	5
Chloroform	1	5	1	5
Chloromethane	3	5	2	5
<i>cis</i> -1,3-Dichloropropene	1	5	1	5
<i>trans</i> -1,3-Dichloropropene	1	5	1	5
Dibromochloromethane	2	5	1	5
1,1-Dichloroethane	2	5	1	5
1,2-Dichloroethane	2	5	2	5
1,1-Dichloroethene	1	5	2	5
1,2-Dichloroethene (total)	2	5	2	5
1,2-Dichloropropane	1	5	3	5
Ethylbenzene	2	5	1	5
2-Hexanone	7	10	3	10
Methylene chloride	2	5	2	5
4-Methyl-2-pentanone	5	10	3	10
Styrene	1	5	1	5
1,1,2,2-Tetrachloroethane	2	5	1	5
Tetrachloroethene	1	5	1	5
Toluene	2	5	1	5
1,1,1-Trichloroethane	1	5	1	5
1,1,2-Trichloroethane	2	5	2	5
Trichloroethene	1	5	1	5
Vinyl chloride	2	5	2	5
Xylenes (total)	1	5	1	5

Note: MDL - method detection limit

MRL - method reporting limit

Table A-11. Quantitation limits for semi-volatile organic compounds

Analyte	Water MDL ($\mu\text{g/L}$)	Water MRL ($\mu\text{g/L}$)	Soil MDL ($\mu\text{g/kg}$)	Soil MRL ($\mu\text{g/kg}$)
Acenaphthene	1	10	33	330
Acenaphthylene	1	10	33	330
Anthracene	1	10	33	330
Benzo(a)anthracene	1	10	33	330
Benzo(b)fluoranthene	1	10	33	330
Benzo(k)fluoranthene	1	10	33	330
bis(2-Chloroethoxy)methane	1	10	67	330
bis(2-chloroethyl)ether	1	10	33	330
bis(2-ethylhexyl)phthalate	2	10	67	330
4-Bromophenyl-phenylether	2	10	33	330
Butylbenzylphthalate	2	10	67	330
di-n-Butylphthalate	2	10	67	330
Carbazole	3	10	33	330
4-Chloroaniline	1	10	67	330
4-Chloro-3-methylphenol	1	10	67	330
2-Chloronaphthalene	1	10	33	330
2-Chlorophenol	1	10	33	330
4-Chlorophenyl-phenyl ether	1	10	33	330
Chrysene	1	10	33	330
Dibenzofuran	1	10	33	330
1,2-Dichlorobenzene	1	10	33	330
1,3-Dichlorobenzene	1	10	33	330
1,4-Dichlorobenzene	1	10	33	330
3,3-Dichlorobenzidine	2	10	67	670
2,4-Dichlorophenol	1	10	67	330
Diethylphthalate	2	10	67	330
2,4-Dimethylphenol	1	10	67	330
Dimethylphthalate	2	10	67	330
4,6-Dinitro-2-methylphenol	5	25	170	830
2,4-Dinitrophenol	20	60	670	2000
2,4-Dinitrotoluene	1	10	33	330
2,6-Dinitrotoluene	2	10	33	330
Fluoranthene	1	10	33	330
Fluorene	1	10	33	330
Hexachlorobenzene	2	10	33	330
Hexachlorobutadiene	2	10	67	330
Hexachlorocyclopentadiene	5	25	170	670
Hexachloroethane	1	10	33	330
Isophorone	1	10	33	330
2-Methylnaphthalene	1	10	33	330
2-Methylphenol	1	10	33	330
4-Methylphenol	3	10	67	330
Naphthalene	1	10	33	330
2-Nitroaniline	2	10	67	330
3-Nitroaniline	2	10	67	330
4-Nitroaniline	2	10	67	330
Nitrobenzene	1	10	33	330
2-Nitrophenol	1	10	67	330
4-Nitrophenol	10	50	170	830
n-Nitroso-di-n-propylamine	1	10	33	330
n-Nitroso-diphenylamine	1	10	33	330
di-n-Octylphthalate	2	10	67	330

Table A-11. (cont.)

Analyte	Water MDL ($\mu\text{g/L}$)	Water MRL ($\mu\text{g/L}$)	Soil MDL ($\mu\text{g/kg}$)	Soil MRL ($\mu\text{g/kg}$)
2,2-Oxybis (1-chloropropane)	1	10	33	330
Pentachlorophenol	3	25	170	830
Phenanthrene	1	10	33	330
Phenol	1	10	67	330
Pyrene	1	10	33	330
1,2,4-Trichlorobenzene	1	10	33	330
2,4,5-Trichlorophenol	2	10	67	330
2,4,6-Trichlorophenol	2	10	67	330

Note: MDL - method detection limit

MRL - method reporting limit

Table A-12. Quantitation limits for PCBs

Compound	Water	Water
	MDL ($\mu\text{g/L}$)	MRL ($\mu\text{g/L}$)
Aroclor [®] 1016	0.1	0.5
Aroclor [®] 1221	0.1	0.5
Aroclor [®] 1232	0.1	0.5
Aroclor [®] 1242	0.1	0.5
Aroclor [®] 1248	0.1	0.5
Aroclor [®] 1254	0.1	0.5
Aroclor [®] 1260	0.1	0.5

Note: MDL - method detection limit
MRL - method reporting limit
PCB - polychlorinated biphenyl

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Table A-13. Quantitation limits for organochlorine pesticides

Compound	Water	Water
	MDL ($\mu\text{g/L}$)	MRL ($\mu\text{g/L}$)
Aldrin	0.002	0.01
α -BHC	0.002	0.01
β -BHC	0.002	0.01
γ -BHC	0.002	0.01
δ -BHC	0.002	0.01
α -Chlordane	0.002	0.01
γ -Chlordane	0.002	0.01
p,p'-DDE	0.004	0.02
p,p'-DDT	0.004	0.02
p,p'-DDT	0.004	0.02
Dieldrin	0.004	0.02
Endosulfan I	0.004	0.02
Endosulfan II	0.002	0.01
Endosulfan sulfate	0.004	0.02
Endrin	0.004	0.02
Endrin aldehyde	0.004	0.02
Endrin ketone	0.004	0.02
Heptachlor	0.002	0.01
Heptachlor epoxide	0.002	0.01
Methoxychlor	0.02	0.1
Toxaphene	0.2	1

Note: MDL - method detection limit

MRL - method reporting limit

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Table A-14. Quantitation limits for TAL inorganics

Analyte	Water MDL (mg/L)	Water MRL (mg/L)	Soil MDL (mg/kg)	Soil MRL (mg/kg)
Aluminum	0.077	0.2	2.6	30
Antimony	0.0084 ^a	0.01 ^a	0.54	1
Arsenic	0.00115 ^b	0.010 ^b	0.25	1
Barium	0.0022	0.1	0.19	10
Beryllium	0.0019	0.01	0.13	0.5
Cadmium	0.00081 ^a	0.0015 ^a	0.76	0.1
Calcium	0.044	0.2	5	30
Chromium	0.0017 ^a	0.003 ^a	0.084	0.5
Cobalt	0.0066	0.05	0.63	5
Copper	0.0035	0.025	0.32	4
Cyanide	0.004 ^c	0.005 ^c	0.18 ^c	0.5 ^c
Iron	0.011	0.1	1.9	20
Lead	0.0079 ^a	0.01 ^a	0.53	1
Magnesium	0.08	0.1	6.7	25
Manganese	0.0026	0.01	0.25	2
Mercury	0.0001 ^d	0.0002 ^d	0.015 ^e	0.1 ^e
Nickel	0.0066	0.05	1.7	5
Potassium	0.199	0.5	22	50
Selenium	0.0044 ^a	0.01 ^a	0.46	1
Silver	0.0056	0.02	0.23	2
Sodium	0.109	0.6	7.4	100
Thallium	0.0092 ^a	0.02 ^a	0.63	2
Vanadium	0.0034	0.02	0.18	2
Zinc	0.0047	0.025	1.8	10

Note: TAL - target analyte list

^a By EPA Method 6010B Trace

^b By EPA Method 7060A

^c By EPA Method 335.2

^d By EPA Method 7470A

^e By EPA Method 7471A

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Table A-15. Method reporting and detection limits for conventional analytes

Analyte	Method	Water MDL (mg/L)	Water MRL (mg/L)	Soil MDL (mg/kg)	Soil MRL (mg/kg)
Alkalinity	EPA 310.1	0.37	1	--	--
Ammonia nitrogen	EPA 350.2	0.15	1	5.2	20
Chloride	EPA 300.0	1.5	2	15	20
Sulfate	EPA 300.0	1.5	5	15	50
Silica	EPA 370.1	0.024	0.1	-- ^a	-- ^a
Total dissolved solids	EPA 160.2	6.14	30	--	--
Percent solids	EPA 160.3	--	--	--	--
Specific gravity (density)	ASTM 1429-95	--	--	--	--
Hexavalent chromium	EPA 7196A	0.003	0.01	0.13	1
Arsenic (III / V)	EPA 1632A	.00001 / .00002	.00005 / .0001	--	--
COD	EPA 410.4	6.41	50	--	--

Note: -- - not applicable
 COD - chemical oxygen demand
 EPA - U.S. Environmental Protection Agency
 MDL - method detection limit
 MRL - method reporting limit

^a Limit depends on amount of sample used in analysis.

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Attachment A-1

Health and Safety Plan Addendum

AR301976

Health and Safety Plan Addendum to the Site-Wide Health and Safety Plan for the Avtex Fibers Superfund Site, Front Royal, Virginia

Introduction

This document is a health and safety plan (HASP) addendum to the site-wide HASP for the Avtex Fibers Superfund Site (Site), Front Royal, Virginia, dated September 1999. The Site-Wide HASP was prepared by FMC Corporation and presents site information, including the location, contacts, background, scope of work, site visitor requirements, chemical and physical hazards, medical surveillance requirements, site and emergency control, work zones, personal protective equipment, air monitoring, decontamination procedures, and general safety and emergency procedures. Site workers will be required to conform to the requirements of the Site-Wide HASP and the additional task-specific requirements contained in this addendum.

This addendum was prepared to address health and safety issues for field work outlined in the Exponent Field Sampling and Analysis Plan (FSAP), to which this HASP is appended. The following field activities are covered by this addendum:

- Monitoring well installation in overburden (hollow-stem auger drilling) and bedrock (reverse-circulation air-rotary drilling)
- Groundwater sampling downgradient of the plant area using a Geoprobe[®] rig
- Site-wide groundwater sampling and collection of water-level measurements
- Wellpoint installation and pore-water sampling; and collection of solid samples within viscose basins 9, 10, and 11 using a hollow-stem auger drill rig
- Hydrological testing (single-well pump tests and infiltrometer tests) at viscose basins 9, 10, and 11.

Task Hazard Analysis

The chemical hazards present at the site were evaluated using data from 1994. A list of chemical hazards and permissible exposure limits is presented in Table 1, along with the range of concentrations observed in groundwater, viscose basin pore water, and viscose

waste material. Chemicals that will be used onsite to decontaminate equipment and preserve samples are listed in Table 1.

The significant chemical hazards present (inhalation and skin/eye contact) are carbon disulfide, acetone, methylene chloride, and hydrogen sulfide. Other chemicals that pose a hazard for incidental ingestion include bis(2-ethylhexyl) phthalate, polychlorinated biphenyls (PCBs; plant area only), metals, and cyanide. The risk of chemical exposures for workers performing field activities within viscose basins 9, 10, and 11 is greater than for those performing work outside the basins, due to the potential for prolonged contact with the waste viscose. For this reason, requirements for use of personal protective equipment (PPE) are different for workers in the basins and those outside the basins. The procedures that will be used to minimize physical hazards are presented in the following sections.

Potential physical hazards of site activities include heat stress, slips within the viscose basins, soft ground properties within the viscose basins, and hazards associated with working around a drill rig and Geoprobe[®] rig.

Health and Safety Personnel Responsibilities

The site safety officer (SSO) or the SSO's assistant is responsible for frequently observing drilling operations for compliance with all health and safety procedures. The SSO or assistant will also survey all drilling locations prior to the start of drilling to ensure that the drilling can be conducted safely. The SSO or assistant shall ensure that field activities are performed in accordance with the HSAP, and shall alert the appropriate site personnel in the event of an emergency. The SSO or assistant shall conduct a field safety meeting prior to or at the end of each day's field work to communicate and address safety concerns.

The task-specific field team leaders (FTL) will be responsible for ensuring that workers under their direction conform to the health and safety procedures contained in this document. The FTL is responsible for conducting and recording the results of all air monitoring for site chemical hazards. Monitoring shall be conducted at the start of each day, when a new borehole is started, or when a new groundwater well is sampled. Air monitoring shall be conducted at a frequency that ensures an appropriate level of personal protection.

Site Communications

The SSO and FTLs will have two-way radios or cell phones available on site. If two-way radios are used, radio checks initiated by the SSO will be performed at the beginning of each day and periodically throughout the day. Radio checks will be documented in the SSO's site log book.

Work Zones

Exclusion zones will be established with stakes, flagging, and/or cones so that a 10-foot perimeter is created around all sampling activities. In the viscose basins, a barrier may be placed on the access roads leading to the work area. A contamination reduction zone will be marked with stakes, flagging, and/or cones, and will be placed immediately adjacent to the exclusion zone. The support zone will consist of all areas outside the exclusion and contamination reduction zone.

Heat Stress

PPE requirements for this field investigation and the likelihood that the sampling will occur in the summer makes heat stress a significant physical hazard for all field activities. Heat stress will be monitored using the employee's heart rate and body temperature, following the procedures in SOP 420 (attached). In an effort to prevent heat stress, shade tarps will be used where feasible to shield workers from the sun. If needed, cool vests may be used underneath PPE coveralls.

An important factor in preventing heat stress is ensuring that workers are drinking enough water to replenish body fluids lost through sweating. To ensure that employees working within the exclusion zone can drink water without risking contact with contaminants, a cooler will be provided containing small volume single-use water containers. The single-use water bottles can be accessed after workers remove their contaminated gloves and don clean latex gloves. After removing a bottle from the cooler, the bottle should be consumed in its entirety and discarded. All partially consumed water bottles will be discarded and should not be placed back into the water cooler.

Personal Protective Equipment

The following section presents task-specific PPE that will be used in addition to the equipment specified in the Site-Wide HASP (Section 7).

Personal Protective Clothing

The modified level D and level C equipment lists for all field activities, excluding sample handling and decontamination, will include rubber safety-toed boots, polyethylene-coated Tyvek® QC coveralls (hooded), and outer Protector™ nitrile/natural rubber gloves, with inner latex gloves. Drillers will wear outer work gloves (to be disposed of at the end of drilling) over outer nitrile gloves (6 mil) with inner latex gloves. All employees working within viscose basins 9, 10, and 11 will wear 4H® booties inside their rubber safety-toed boots. All wrist and ankle joints will be sealed and secured with duct tape.

Onsite personnel who will be handling samples (including staff recording information into logbooks) and performing onsite decontamination will use the equipment described

above, with the exception of the gloves. Personnel handling samples will use outer nitrile gloves (6 mil) with inner latex gloves. Staff involved in decontamination activities will use North SilverShield® gloves.

Respiratory Protection

Modified level D protective equipment is expected to be used for all sampling activities. Air monitoring will be performed, and if it is necessary to upgrade to Level C, full-face air-purifying respirators will be available for each employee. The full-face respirators will be equipped with organic vapor/acid gas/P95 particulate filter cartridges. Upon finalization of the project schedule and selection of the project field team, a memo will be attached to this addendum outlining the specific respirator models and cartridges that will be used during the field activities. The memo will also provide specific change schedules for all cartridges.

Level B work is not expected nor covered by this HASP addendum. If air monitoring indicates that Level B work is needed, and engineering controls (i.e., fans) are not effective in reducing concentrations to Modified D or C action levels, then the area will be vacated and an alternative plan will be developed to safely complete the work activity.

Personal Air Monitoring

The following items will be used to monitor chemical exposure onsite. Action levels for site activities are presented in the following section.

Items used to monitor chemical exposure onsite

Site Chemicals	Monitoring Instrument
Carbon disulfide, acetone, and minor organic compounds present onsite	Photovac MicroTip HL-2000 (10.6 ev lamp) photo ionization detector (PID) calibrated to 100 ppm isobutylene gas and programmed to a response factor (RF) of 1.4 (carbon disulfide). Note: acetone RF = 1.2, hydrogen sulfide RF = 3.7
Hydrogen sulfide and combustible gases	Industrial Scientific Corporation ATX612 multi-gas monitor (O2, lower explosive limit or LEL, H2S, CO)
Total dust (assumed to be equal to total respirable dust for this project); BEHP, PCBs and metals present in dust	MIE miniram
Hydrogen sulfide and methylene chloride	Sensidyne® gas sampling system with chemical-specific detector tubes
Carbon disulfide	Drager pump and detector tubes
Carbon disulfide and hydrogen sulfide	Chromair™ colorimetric badges (8-hr TWA concentrations)

Action Levels

The following section presents action levels that will be used onsite to guide the selection of PPE levels. The photoionization detector (PID), multi-gas meter, and MIE miniram will be used for the initial determination of airborne chemicals. Depending on the results of this screen, other sampling methods may be required to select the appropriate level of PPE. All workers will be outfitted initially with modified level D apparel. Exceedances of action levels will cause employees to upgrade to level C or to vacate the work area. The action levels are summarized in the following table, along with procedures to address action-level exceedances. The action level for respirable dust has been lowered to 4 mg/m^3 (OSHA PEL = 5 mg/m^3), because this is the concentration of dust in air where lead concentrations would exceed the PEL for lead, assuming that concentrations in waste viscose would be similar to concentrations in dust generated from the waste viscose.

Drilling Operations

The onsite drill team leader shall visually inspect all drill rigs at the start of the day to ensure that equipment is in good working condition. If repairs are needed, they will be performed prior to restarting the drilling program. All drill rigs shall be equipped with a Class ABC fire extinguisher, and field staff shall be aware of the fire danger that the field equipment poses to vegetation. Utility clearances will be performed for all drill holes prior to the start of the field investigation. Drill rigs and field sampling activities shall be situated such that the borehole is located downwind of all staff. This will minimize the potential for chemical exposure and will direct volatiles and gases away from workers.

In an event of a drill rig collapse, the drill rig operator will shut down the drill rig (if it can be performed safely) and the field staff will contact the SSO. The SSO will inform the site manager and initiate emergency response procedures, if required.

When drilling in the viscose basins, plywood or some other type of material may be needed under the tires of the drill rig to keep the rig from sinking. If this is required, the rig shall be placed in park while boards are maneuvered in front of it. The rig shall remain in park until the operator can visually account for all field staff, who will assemble on the driver's side of the rig.

Action levels to guide the selection of PPE levels

Monitoring Instrument	Compound	Action Level	Response
Multi-gas meter (set alarm at 10 ppm)	Hydrogen sulfide	≥ 10 ppm	Leave area (go upwind) and attempt to ventilate work area. If still greater than 10 ppm, then leave work area and contact site safety officer.
Multi-gas meter (set alarm at 10% of LEL)	Combustible gas (applicable to drilling only)	10%–20% of LEL	Use non-sparking tools and continue to monitor.
Multi-gas meter (set alarm at 10% of LEL)	Combustible gas (applicable to drilling only)	$\geq 20\%$ of LEL	Shut down drill rig and leave area (go upwind). Attempt to ventilate the work area. If concentrations do not dissipate, stay clear of the work area and contact the SSO.
MIE miniram	Dust	$\geq 4 \text{ mg/m}^3$	Upgrade to Level C.
MIE miniram	Dust	$\geq 400 \text{ mg/m}^3$	Leave site and contact SSO.
PID	Carbon disulfide	≥ 10 ppm	Use a detector tube to determine the concentration of methylene chloride and carbon disulfide. If carbon disulfide is between 10 ppm and 60 ppm and methylene chloride is less than 25 ppm, then upgrade to Level C and continue working.
Draeger tubes	Carbon disulfide	≥ 60 ppm	Leave site and contact the SSO.
Sensidyne® tubes	Methylene chloride	≥ 25 ppm	Leave site and contact the SSO.
Chromair™ colorimetric badge	Carbon disulfide	>10 ppm concentration in <8 hours	Upgrade to level C for the remainder of the task work activity.
Chromair™ colorimetric badge	Hydrogen sulfide	>10 ppm concentration in <8 hours	Leave site for the day and contact the SSO.

TABLE 1. CHEMICAL HAZARD ANALYSIS

Potentially hazardous chemicals known or suspected to be onsite (including preservatives and decontamination chemicals):

Site Chemical Data							Chemical Characteristics					Potential Chemical Routes						
Chemical	Medium	Observed or Expected Concentration (Enter units of ppm or mg/m³)	OSHA or NIOSH PEL (Enter units of ppm or mg/m³)	OSHA or NIOSH STEL (Enter units of ppm or mg/m³)	OSHA IDLH (Enter units of ppm or mg/m³)	Odor Threshold (ppm)	IP (eV)	Corrosive	(F)lammable, (C)omustible	Explosive	Radioactive	Biological agent	Particulates or fibers	Inhalation	Ingestion	Skin absorption	Skin contact	Eye contact
VOCs, SVOCs, Organochlorine Pesticides/PCBs																		
Acetone	GW	1-3.4 mg/L	1,000 ppm	NA	2,500 ppm	4.6	9.69		F					X	X		X	X
Acetone	VB Pore Water	10-340 mg/L	1,000 ppm	NA	2,500 ppm	4.6	9.69		F					X	X		X	X
Carbon Disulfide	GW	0.3-1,700 mg/L	10 ppm	10 ppm [skin]	500 ppm	0.096	10.08		F					X	X	X	X	X
Carbon Disulfide	VB Pore Water	180-3,431 mg/L	10 ppm	10 ppm [skin]	500 ppm	0.096	10.08		F					X	X	X	X	X
Carbon Disulfide	Waste Viscose	0.02-20,000 mg/kg	10 ppm	10 ppm [skin]	500 ppm	0.096	10.08		F					X	X	X	X	X
Methylene Chloride	GW	0.001-4.3 mg/L	25 ppm	125 ppm	2,300 ppm	0.912	11.32		C					X	X	X	X	X
Methylene Chloride	VB Pore Water	20-135 mg/L	25 ppm	125 ppm	2,300 ppm	0.912	11.32		C					X	X	X	X	X
Methylene Chloride	Waste Viscose	0.2-450 mg/kg	25 ppm	125 ppm	2,300 ppm	0.912	11.32		C					X	X	X	X	X
Bis(2-ethylhexyl)phthalate [BEHP]	GW	0.001-0.61 mg/L	5 mg/m³	10 mg/m³	5,000 mg/m³	NA	?		C						X		X	X
PCBs (plant area)	GW	Unknown	0.5 mg/m³ [skin]	NA	5 mg/m³	NA	?		F					X	X	X	X	X
Hydrogen Sulfide	GW	Unknown	10 ppm ceiling [10-min]	NA	100 ppm	0.0005	10.46		X					X			X	X

Site Chemical Data										Chemical Characteristics						Potential Chemical Routes				
Chemical	Observed or Expected Concentration (Enter units of ppm or mg/m ³)	OSHA or NIOSH PEL (Enter units of ppm or mg/m ³)	OSHA or NIOSH STEL (Enter units of ppm or mg/m ³)	OSHA IDLH (Enter units of ppm or mg/m ³)	Odor Threshold (ppm)	IP (eV)	Corrosive	(F)lammable, (C)omustible	Explosive	Radioactive	Biological agent	Particulates or fibers	Inhalation	Ingestion	Skin absorption	Skin contact	Eye contact			
Hydrogen Sulfide	Medium																			
	VB Pore Water	Unknown	10 ppm ceiling [10-min]	NA	100 ppm	0.0005		X					X			X	X			
Hydrogen Sulfide	Waste Viscose	Unknown	10 ppm ceiling [10-min]	NA		0.0005		X					X			X	X			
	Well borings & Waste Viscose												X			X	X			
Total Particulate Dust		Unknown	4 mg/m ³	NA		NA							X							
METALS																				
Arsenic	Waste Viscose	0.2-59 mg/kg	0.5 mg/m ³	NA		NA							X	X		X	X			
Lead	Waste Viscose	3-5,950 mg/kg	0.1 mg/m ³	NA		100 mg/m ³ as Pb							X	X		X	X			
Arsenic	GW	0.001-8 mg/L	NA to H20	NA to H20		NA								X		X	X			
Lead	GW	0.003-0.24 mg/L	NA to H20	NA to H20		NA								X		X	X			
Antimony	GW	0.013-1.8 mg/L	NA to H20	NA to H20		NA								X		X	X			
Barium	GW	0.001-7.4 mg/L	NA to H20	NA to H20		NA								X		X	X			
Cadmium	GW	0.001-0.09 mg/L	NA to H20	NA to H20		NA								X		X	X			
Chromium	GW	0.003-1.4 mg/L	NA to H20	NA to H20		NA								X		X	X			
Mercury	GW	0.0002-0.18 mg/L	NA to H20	NA to H20		NA								X		X	X			
Nickel	GW	0.005-1.92 mg/L	NA to H20	NA to H20		NA								X		X	X			
Thallium	GW	0.001-0.024 mg/L	NA to H20	NA to H20		NA								X		X	X			
Vanadium	GW	0.002-1.0 mg/L	NA to H20	NA to H20		NA								X		X	X			

Site Chemical Data										Chemical Characteristics					Potential Chemical Routes				
Chemical	Medium	Observed or Expected Concentration (Enter units of ppm or mg/m ³)	OSHA or NIOSH PEL (Enter units of ppm or mg/m ³)	OSHA or NIOSH STEL (Enter units of ppm or mg/m ³)	OSHA IDLH (Enter units of ppm or mg/m ³)	Odor Threshold (ppm)	IP (eV)	Corrosive	(F)lammable, (C)omustible	Explosive	Radioactive	Biological agent	Particulates or fibers	Inhalation	Ingestion	Skin absorption	Skin contact	Eye contact	
Zinc	GW	0.004-11.4 mg/L	NA to H20	NA to H20	NA to H20	NA	NA								X		X	X	
Cyanide, total	GW	0.003-5.1 mg/L	NA to H20	NA to H20	NA to H20	NA	NA								X		X	X	
DECONTAMINATION CHEMICALS																			
Nitric Acid	Decon	10 percent	2 ppm	4 ppm	25 ppm	0.27	11.95	X						X	X		X	X	
Acetone	Decon	Concentrated	1,000 ppm	NA	2,500 ppm	4.58	9.69		F					X	X		X	X	
Hexane	Decon	Concentrated	250 ppm	NA	1,100 ppm	21.9	10.18		F					X	X		X	X	
PRESERVATIVES																			
Nitric Acid	2 mL per bottle	Concentrated	2 ppm	4 ppm	25 ppm	0.27	11.95	X						X	X		X	X	
Hydrochloric Acid	2 mL per bottle	Concentrated	5 ppm [ceiling]	NA	50 ppm	6.3	12.74	X						X	X		X	X	
Sodium Hydroxide	2 mL per bottle	Concentrated	2 mg/m ³	NA	10 mg/m ³	NA	NA	X						X	X		X	X	
Sulfuric Acid	2 mL per bottle	Concentrated	1 mg/m ³	NA	15 mg/m ³	0.15	?	X						X	X		X	X	

AR301985

Standard Operating Procedure

Heat Stress Prevention And Monitoring SOP 420

Introduction

Heat stress poses a serious threat to the health of workers conducting hazardous material or chemical investigations at industrial and other facilities. This threat is increased for workers wearing chemical protective clothing or personal protective equipment (PPE) because the impermeable clothing does not allow sweat to evaporate and cool the body. Depending on ambient conditions, the work being performed, and other factors, heat stress may affect workers at temperatures as low as 70°F (adjusted for humidity and sunlight; see *Monitoring for Heat Stress*, below) and can occur rapidly, with workers suffering acute symptoms in less than 15 minutes. Even relatively minor symptoms of heat stress can result in impaired functional ability, threatening the safety of the worker and his or her companions. Thus, heat stress can present as great a health risk to workers as chemical hazards or traditional physical hazards such as falling objects and confined spaces. This SOP presents information on heat-related illnesses, factors that influence heat stress, monitoring for heat stress, and heat stress prevention.

Heat-Related Illnesses

A common factor in heat-related illnesses is the failure of the worker to recognize the symptoms of heat stress. All personnel should become familiar with the symptoms of heat stress and appropriate first aid precautionary measures.

Table 420-1 provides information on the types of heat-related disorders and procedures for treating them. Heat stress can result in minor symptoms such as heat rash, heat cramps, discomfort, and drowsiness. Prolonged heat stress can result in more severe effects, such as heat exhaustion and heat stroke. Heat rash is a relatively minor form of early heat stress that results from prolonged contact with wet clothing. Heat rash can be prevented by allowing the skin to dry completely during rest periods and by showering as soon as possible at the end of the work day. Although heat cramps and drowsiness are generally of minor concern, these symptoms may also result in impaired functional ability, which in turn may threaten the safety of the individual and coworkers.

Heat cramps, heat syncope, heat exhaustion, and heat stroke all result from excessive loss of body fluids and electrolytes. The symptom of heat cramps is spasms in the abdomen or

TABLE 420-1. HEAT DISORDERS

Disorder	Cause	Signs	Treatment
Heat rash	Heavy sweating, drinking large volumes of water without replacing salt loss	Profuse tiny raised vesicles, prickly skin	Remove from source of heat; allow skin to dry completely during rest periods; shower as soon as possible after work day
Heat syncope	Lack of acclimatization, pooling of blood in the legs	Fainting while standing, immobile in heat	Remove to cooler area
Heat cramps	Heavy sweating, drinking large volumes of water without replacing salt loss	Painful spasms of muscles used during work; cool, moist skin	Provide fluids that replace salts and protein; allow 1–3 days of rest, depending on the severity of the attack
Heat exhaustion	Sustained exertion in heat, lack of acclimatization, failure to replace water and/or salt	Fatigue, nausea, headache, moist and clammy skin, pale complexion, delirium, diarrhea, cramps	Remove to cooler area; provide cool water and salted fruit or protein drinks
Heat stroke	Sustained exertion in heat, excessive exposure to heat, lack of physical fitness, alcoholism and drug abuse, dehydration, cardiovascular disease	Headache; rapid pulse; dizziness; nausea; confusion; convulsions; flushed, dry skin; high body temperature; loss of consciousness; coma	Call emergency medical services (often 911) immediately; place the worker in a cool, shady area; remove their clothing, then sprinkle their entire body with cool water; also cool by fanning; treat for shock

limbs. Heat syncope is a pooling of blood in the lower extremities, which may result in fainting when the worker stands up suddenly or has been immobile. Heat exhaustion, caused by more severe dehydration, has the following symptoms: pale, clammy skin; profuse sweating; weakness; headache; and nausea. Heat stroke (sometimes called sunstroke) is a life-threatening condition that occurs when the body's temperature-regulating system no longer functions properly. Heat stroke requires immediate medical attention. Symptoms of heat stroke include hot, dry skin; a high fever (often 106°F or more); dizziness; nausea; rapid pulse; and unconsciousness. Brain damage and death may follow if the body temperature is not reduced.

Workers must learn to recognize that dizziness, nausea, headaches, skin rashes, muscle cramps, and pale or clammy skin are symptoms of heat stress and act promptly when suffering these symptoms. Workers may not realize the risk they face by ignoring these symptoms and staying in the work area until overcome by heat stress or suffer other injuries of heat stress-related impairment. Critical factors in the prevention of heat stress

include a proper work regimen and the intake of adequate replacement fluids and electrolytes.

Factors Influencing Heat Stress

Many factors determine an individual's susceptibility to heat stress. Environmental factors include the ambient temperature, humidity, and presence or absence of cooling breezes or shade. The nature of the work being performed, including the level of physical activity, the degree of permeability and the number of layers of protective clothing, and the time of day that the work is being performed affects the level of heat stress.

Some workers are predisposed towards suffering heat stress. Factors that could increase a worker's susceptibility to heat stress include degree of physical fitness, lack of acclimatization, age, dehydration, obesity, alcohol and drug use, infection, sunburn, diarrhea, and chronic disease.

Workers who have acclimated to working in hot climates or in PPE will be less likely to suffer heat stress. Acclimated individuals typically have lower heart rates and body temperatures than nonacclimated workers. Acclimated workers also sweat sooner and more profusely than those not acclimated to high temperatures or the use of PPE (acclimated individuals may sweat more profusely when wearing PPE than nonacclimated workers, thus increasing their risk of dehydration). The National Institute of Occupational Safety and Health (NIOSH) recommends a progressive 6-day regimen to allow a worker to acclimate to work in a hot environment, especially when wearing PPE (this program begins with 50-percent exposure, then lengthens the staying time by 10 percent each subsequent day). A individual's capacity to work in hot environments generally decreases with age. According to NIOSH, however, an older person in peak physical condition may have a greater work capacity than a less fit, younger worker. Thus, physical fitness is a more significant factor than age when determining an individual's work capacity. Weight is usually a significant factor when determining the ability of an individual to work in a heated environment because overweight people have a lower surface area to mass ratio and, thus, can not dissipate heat as well as slimmer people. Weight is not as significant a factor when wearing PPE, as the impermeable garments impede the dissipation of body heat regardless of the individual's weight.

Monitoring For Heat Stress

To ensure the safety of workers wearing impermeable or semipermeable encapsulating PPE, NIOSH recommends that heat stress monitoring be implemented at temperatures above 70°F, using an "adjusted temperature." The adjusted temperature is calculated by determining the ambient temperature (using a standard thermometer, shielded from heat) and adding the total of $13 \times$ the percentage of sunshine (complete overcast = 0 percent sunshine and no cloud cover = 100 percent sunshine). For example, for an ambient temperature of 80°F and 80 percent sunshine, the adjusted temperature would be 90.4°F

$(80 + [13 \times 0.80] = 90.4)$. The effect of heat stress on the body may be monitored using the techniques described below. Recommended intervals for physiological monitoring when wearing permeable or impermeable work clothes are shown in Table 420-2.

TABLE 420-2. SUGGESTED FREQUENCY OF PHYSIOLOGICAL MONITORING FOR FIT AND ACCLIMATIZED WORKERS^a

Adjusted Air Temperature ^b	Normal Work Ensemble ^c	Impermeable Ensemble
90°F or above (32.2°C)	After each 45 minutes of work	After each 15 minutes of work
87.5°–90°F (30.8°–32.2°C)	After each 60 minutes of work	After each 30 minutes of work
82.5°–87.5°F (28.1°–30.8°C)	After each 90 minutes of work	After each 60 minutes of work
77.5°–82.5°F (25.3°–28.1°C)	After each 120 minutes of work	After each 90 minutes of work
72.5°–77.5°F (22.5°–25.3°C)	After each 150 minutes of work	After each 120 minutes of work

Source: NIOSH (1985).

^a For work level of 250 kilocalories/hour (moderate work activity).

^b Calculate the adjusted air temperature ($t_{a\text{ adj}}$) by using this equation: $t_{a\text{ adj}}^{\circ}\text{F} = t_a^{\circ}\text{F} + (13 \times \text{percent sunshine})$. Measure air temperature (t_a) with a standard, mercury-in-glass thermometer, with the bulb shielded from radiant heat. Estimate percent sunshine by judging what percent of time the sun is not covered by clouds that are thick enough to produce a shadow (100 percent sunshine = no cloud cover and sharp, distinct shadows; 0 percent sunshine = no shadows).

^c A normal work ensemble consists of cotton coveralls or other cotton clothing with long sleeves and pants.

Heart Rate

To monitor the effect of heat stress on the worker using the heart rate method, the worker must measure his or her heart rate over a 30-second period as soon as possible at the beginning of each rest break. The pulse should be taken at the radial (wrist) artery, not the carotid (neck) artery. When monitoring heart rate, the following guidelines apply:

- If the worker's heart rate does not exceed 110 beats/minute, proceed as before

- If the worker's heart rate exceeds 110 beats/minute at the beginning of the rest period, shorten the next work cycle by one-third and keep the rest period the same
- If the worker's heart rate exceeds 110 beats/minute at the beginning of the next rest period, shorten the next work cycle by another one-third.

Exponent recommends the use of heart rate monitoring as the minimum heat stress monitoring technique.

Body Temperature

To monitor the effect of heat stress on the worker using the body temperature method, the worker should use a clinical thermometer (3 minutes under the tongue) or a ear thermometer at the end of each work period, but before taking a drink. When monitoring body temperature, the following guidelines apply:

- If the body temperature does not exceed 99.6°F, no action is needed
- If the body temperature exceeds 99.6°F at the beginning of the rest period, shorten the next work cycle by one-third and keep the rest period the same
- If the body temperature exceeds 99.6°F at the beginning of the next rest period, shorten the following work period by one-third
- If the body temperature exceeds 100.6°F at the beginning of any rest period, the worker should not be permitted to wear impermeable clothing.

Body Water Loss

To monitor the effect of heat stress on workers by measuring body water loss, the workers must weigh themselves with a scale accurate to within 0.25 lb at the beginning and end of each work day. Their weight for the beginning and the end of the work shift should be taken while wearing similar clothing or, for greatest accuracy, when nude. Fluctuations in weight (between the beginning of the shift and end of the shift) indicate the gain or loss of body fluids, thus revealing if fluid replenishment has been effective. Body weight loss in a work day should not exceed 1.5 percent of total body weight. Where such weight losses occur, more attention should be given to fluid replacement during subsequent work shifts.

Electronic Monitors

Electronic monitors that constantly monitor a worker's heart rate and core temperature have recently been developed. These devices utilize sensors that are held in place on the worker's chest with an elastic band and are programmed to account for the worker's age and type of protective clothing. The worker's heart rate and core temperature are monitored, and lights illuminate on a small pad (worn on the outside of the PPE) to indicate one of the following conditions: the worker may continue as before, the worker has only a limited amount of work time left, or the worker should exit the work area immediately. These devices also include audible alarms and can be set to download heat stress data to a printer at the end of a shift.

Other electronic monitors are designed to measure adjusted (ambient) temperatures and can be programmed to account for the level of worker activity and type of protective clothing. These devices can calculate stay times (the amount of time the workers in the area may remain in that area at the current activity levels) and can also log conditions encountered. These devices do not actually monitor the effects of heat stress on the workers, but may be used to implement heat stress prevention measures.

Heat Stress Prevention

Several means are available to decrease or prevent the effects of heat stress.

An effective means of preventing heat stress is to schedule work in the cool parts of day—early mornings, evenings, or at night. If the heat source is mechanical (e.g., caused by a power plant or production equipment), it may be possible to schedule the work during hours when the facility is inoperative.

Engineering methods may be used to cool workers regardless of the time of day. These methods frequently involve the use of cool vests (ice packs worn under PPE in a special vest), circulating air (often associated with powered air-purifying respirators that utilize hoods rather than sealed facepieces), or in extreme cases, circulating liquids through specially designed suits. Other engineering controls to prevent heat stress include erecting a shelter to protect workers from direct sunlight or the circulation of air through the work place. In some instances, deluge showers can be constructed within the exclusion zone or in the decontamination area that allow workers wearing fully encapsulating PPE to stand under a shower of cold water. The deluge shower is an efficient means of providing relief to the worker without requiring the worker to proceed through decontamination and exit from the work area.

A critical element in an effective heat stress prevention program is to ensure that workers maintain a normal level of fluids within their bodies. To prevent heat-related illness, the worker's intake of fluids must approximate the amount of fluid lost (e.g., the worker must drink 8 oz of water for every 8 oz decrease in body weight). The sensation of thirst is not a reliable indicator of fluid loss. When heavy sweating occurs, it is essential that workers increase their fluid intake. The following guidelines may be useful:

- Provide fluid replenishment beverages at the work site, cooled to 50–60°F (appropriate beverages include water and diluted fruit juices or Gatorade[®])
- Have workers drink 16 oz of fluid prior to working in a hot environment
- Encourage workers to drink 8–16 oz of liquids every 15–20 minutes, or at each rest break. NIOSH recommends that workers consume a total of 1–1.5 gal of fluids/day, although a greater quantity may be required.

Scheduling rest periods to break up work periods is essential to prevent heat-related illnesses. It is difficult to establish a rigid schedule that spells out the staying time and rest breaks based on temperature alone because other factors, such as the level of physical activity and the type of protective equipment, play a significant role in determining an individual's susceptibility to heat stress. The recommended course of action is to use the guidelines for physiological monitoring provided in Table 420-2 to schedule the initial work period, then vary the length of the break and the next work period based on the physiological responses of individual workers to the work load. If the workers are engaged in strenuous activities, are not acclimated to the work environment, or are not in peak physical condition, the work interval should be shortened significantly, and monitoring continued.

Individual Responsibilities

In preventing heat stress, it is essential that the individual monitor his or her own symptoms and promptly take steps to remedy any signs of heat stress. Such steps include notifying coworkers of his or her condition and taking whatever measures may be necessary to alleviate the symptoms by taking a break, increasing the intake of fluids, instituting environmental controls (such as the use of cool vests or circulating air), assuming less strenuous duties, or implementing appropriate first-aid procedures as indicated in Table 420-1. No field monitoring program can substitute for the individual's sense of their own health and physical limits.

Reference

NIOSH. 1985. Occupational safety and health guidance manual for hazardous waste site activities. Prepared by the National Institute for Occupational Safety and Health, Occupational Safety and Health Administration, U.S. Coast Guard, and U.S. Environmental Protection Agency. U.S. Department of Human and Health Services, Public Health Service, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Washington, DC.

TABLE 1. CHEMICAL HAZARD ANALYSIS

Potentially hazardous chemicals known or suspected to be onsite (including preservatives and decontamination chemicals):

Site Chemical Data							Chemical Characteristics						Potential Chemical Routes					
Chemical	Medium	Observed or Expected Concentration (Enter units of ppm or mg/m³)	OSHA or NIOSH PEL (Enter units of ppm or mg/m³)	OSHA or NIOSH STEL (Enter units of ppm or mg/m³)	OSHA IDLH (Enter units of ppm or mg/m³)	Odor Threshold (ppm)	IP (eV)	Corrosive	(F)lammable, (C)omustible	Explosive	Radioactive	Biological agent	Particulates or fibers	Inhalation	Ingestion	Skin absorption	Skin contact	Eye contact
VOCs, SVOCs, Organochlorine Pesticides/PCBs																		
Acetone	GW	1-3.4 mg/L	1,000 ppm	NA	2,500 ppm	4.6	9.69		F					X	X		X	X
Acetone	VB Pore Water	10-340 mg/L	1,000 ppm	NA	2,500 ppm	4.6	9.69		F					X	X		X	X
Carbon Disulfide	GW	0.3-1,700 mg/L	10 ppm	10 ppm [skin]	500 ppm	0.096	10.08		F					X	X	X	X	X
Carbon Disulfide	VB Pore Water	180-3,431 mg/L	10 ppm	10 ppm [skin]	500 ppm	0.096	10.08		F					X	X	X	X	X
Carbon Disulfide	Waste Viscose	0.02-20,000 mg/kg	10 ppm	10 ppm [skin]	500 ppm	0.096	10.08		F					X	X	X	X	X
Methylene Chloride	GW	0.001-4.3 mg/L	25 ppm	125 ppm	2,300 ppm	0.912	11.32		C					X	X	X	X	X
Methylene Chloride	VB Pore Water	20-135 mg/L	25 ppm	125 ppm	2,300 ppm	0.912	11.32		C					X	X	X	X	X
Methylene Chloride	Waste Viscose	0.2-450 mg/kg	25 ppm	125 ppm	2,300 ppm	0.912	11.32		C					X	X	X	X	X
Bis(2-ethylhexyl)phthalate [BEHP]	GW	0.001-0.61 mg/L	5 mg/m³	10 mg/m³	5,000 mg/m³	NA	?		C						X		X	X
PCBs (plant area)	GW	Unknown	0.5 mg/m³ [skin]	NA	5 mg/m³	NA	?		F					X	X	X	X	X
Hydrogen Sulfide	GW	Unknown	10 ppm ceiling (10-min)	NA	100 ppm	0.0005	10.46		X					X			X	X

Site Chemical Data										Chemical Characteristics					Potential Chemical Routes				
Chemical	Observed or Expected Concentration (Enter units of ppm or mg/m ³)	OSHA or NIOSH PEL (Enter units of ppm or mg/m ³)	OSHA or NIOSH STEL (Enter units of ppm or mg/m ³)	OSHA IDLH (Enter units of ppm or mg/m ³)	Odor Threshold (ppm)	IP (eV)	Corrosive	(F)lammable, (C)omustible	Explosive	Radioactive	Biological agent	Particulates or fibers	Inhalation	Ingestion	Skin absorption	Skin contact	Eye contact		
Hydrogen Sulfide	Medium	Unknown	10 ppm ceiling [10-min]	NA	100 ppm	10.46		X					X			X	X		
Hydrogen Sulfide	Waste Viscose	Unknown	10 ppm ceiling [10-min]	NA	100 ppm	10.46		X					X			X	X		
Hydrogen Sulfide	Well borings & Waste Viscose	Unknown											X			X	X		
Total Particulate Dust	Unknown	4 mg/m ³	NA	N.D.	NA	NA													
METALS																			
Arsenic	Waste Viscose	0.2-59 mg/kg	0.5 mg/m ³	NA	N.D.	NA							X	X		X	X		
Lead	Waste Viscose	3-5,950 mg/kg	0.1 mg/m ³	NA	100 mg/m ³ as Pb	NA							X	X		X	X		
Arsenic	GW	0.001-8 mg/L	NA to H20	NA to H20	NA to H20	NA								X		X	X		
Lead	GW	0.003-0.24 mg/L	NA to H20	NA to H20	NA to H20	NA								X		X	X		
Antimony	GW	0.013-1.8 mg/L	NA to H20	NA to H20	NA to H20	NA								X		X	X		
Barium	GW	0.001-7.4 mg/L	NA to H20	NA to H20	NA to H20	NA								X		X	X		
Cadmium	GW	0.001-0.09 mg/L	NA to H20	NA to H20	NA to H20	NA								X		X	X		
Chromium	GW	0.003-1.4 mg/L	NA to H20	NA to H20	NA to H20	NA								X		X	X		
Mercury	GW	0.0002-0.18 mg/L	NA to H20	NA to H20	NA to H20	NA								X		X	X		
Nickel	GW	0.005-1.92 mg/L	NA to H20	NA to H20	NA to H20	NA								X		X	X		
Thallium	GW	0.001-0.024 mg/L	NA to H20	NA to H20	NA to H20	NA								X		X	X		
Vanadium	GW	0.002-1.0 mg/L	NA to H20	NA to H20	NA to H20	NA								X		X	X		

Site Chemical Data										Chemical Characteristics					Potential Chemical Routes				
Chemical	Medium	Observed or Expected Concentration (Enter units of ppm or mg/m ³)	OSHA or NIOSH PEL (Enter units of ppm or mg/m ³)	OSHA or NIOSH STEL (Enter units of ppm or mg/m ³)	OSHA IDLH (Enter units of ppm or mg/m ³)	Odor Threshold (ppm)	IP (eV)	Corrosive	(F)lammable, (C)omustible	Explosive	Radioactive	Biological agent	Particulates or fibers	Inhalation	Ingestion	Skin absorption	Skin contact	Eye contact	
Zinc	GW	0.004-11.4 mg/L	NA to H20	NA to H20	NA to H20	NA	NA								X		X	X	
Cyanide, total	GW	0.003-5.1 mg/L	NA to H20	NA to H20	NA to H20	NA	NA								X		X	X	
DECONTAMINATION CHEMICALS																			
Nitric Acid	Decon	10 percent	2 ppm	4 ppm	25 ppm	0.27	11.95	X						X	X		X	X	
Methanol	Decon	Concentrated	200 ppm [skin]	250 ppm [skin]	6,000 ppm	4.2-5,900	10.84		F	X				X	X	X	X	X	
PRESERVATIVES																			
Nitric Acid	2 mL per bottle	Concentrated	2 ppm	4 ppm	25 ppm	0.27	11.95	X						X	X		X	X	
Hydrochloric Acid	2 mL per bottle	Concentrated	5 ppm [ceiling]	NA	50 ppm	6.3	12.74	X						X	X		X	X	
Sodium Hydroxide	2 mL per bottle	Concentrated	2 mg/m ³	NA	10 mg/m ³	NA	NA	X						X	X		X	X	
Sulfuric Acid	2 mL per bottle	Concentrated	1 mg/m ³	NA	15 mg/m ³	0.15	?	X						X	X		X	X	

AR301995

Heat Stress Monitoring Record

Project Title/Number _____

Site Name/Location _____

Time Work Started _____ Initial Temperature _____ F° C°

Adjusted temperature at hour: [= Ambient air temp + (13 × % sunshine)]

% sunshine = estimate based on: 100% = no cloud cover, distinct shadows; 0% = no shadows

Time ¹								
Name	Hr/Temp ²							Action Taken ³

1. Time of break
2. Heart rate/body temperature
3. i.e., break lengthened, cool vests worn, etc.

Data collected by _____
Print name *Signature*

Monitoring Guidelines

1. Heart rate--monitor the radial pulse (wrist) as soon as possible at the beginning of the test period.

If the rate exceeds 110 beats per minute, shorten the next work cycle by one-third and keep the rest period the same.

If the heart rate still exceeds 110 beats per minute at the next rest period, shorten the following work one-third.

2. Body temperature--use a clinical thermometer for 3 minutes under the tongue to measure oral temperature or an ear thermometer immediately following the work period (before drinking).

If the temperature exceeds 99.6° F (37.6° C), shorten the next work cycle by one-third without changing the rest period.

If oral temperature still exceeds 99.6° F (37.6° C), at the beginning of the next rest period, shorten the following work cycle by one-third.

If the temperature exceeds 100.6° F (38.1°C), do not permit the worker to wear an impermeable garment.

Attachment A-2

Example Borehole Log and Well Construction Diagram

Exponent"

Sheet of _____

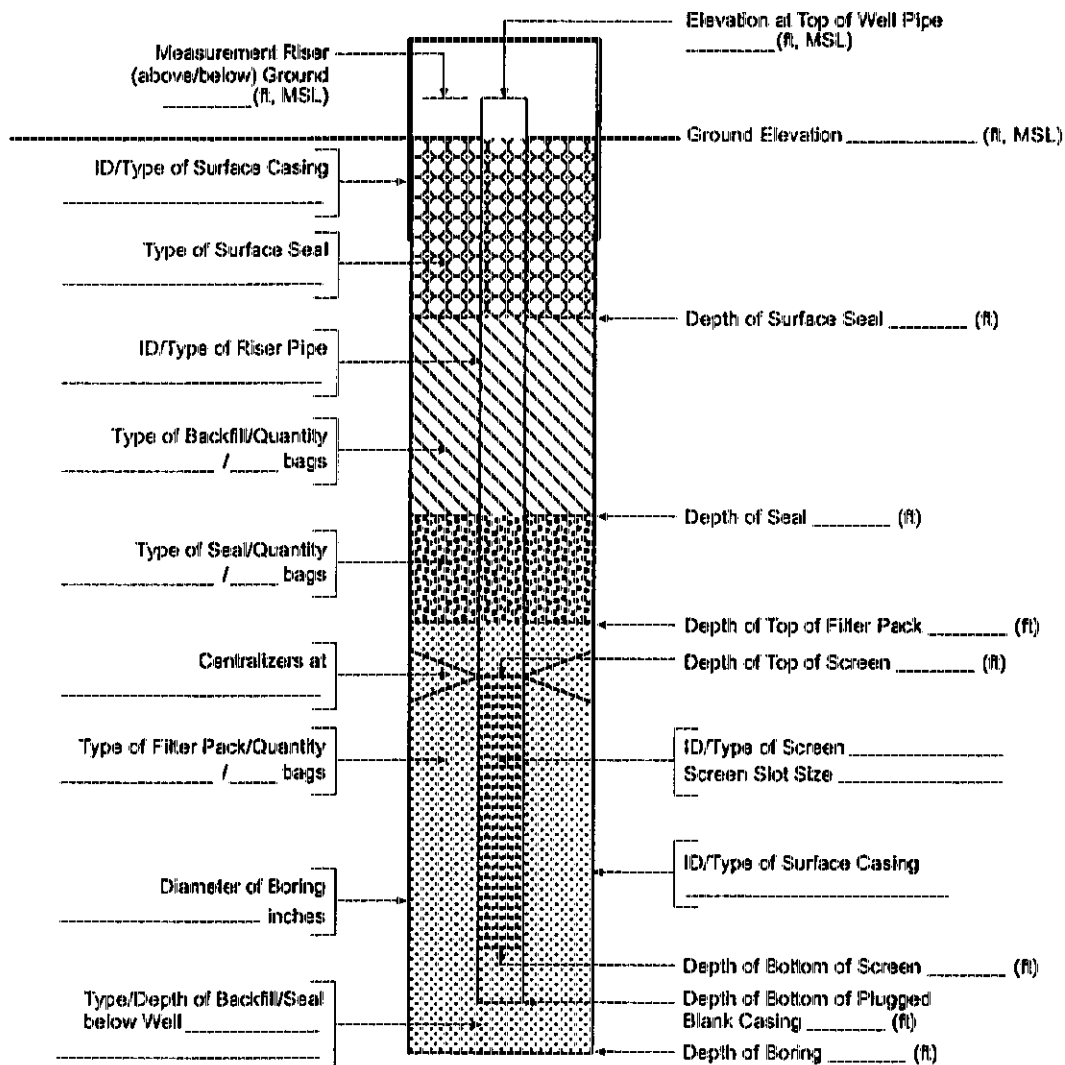
FIELD BOREHOLE LOG RPT#7 499 W/A

AR301998

MONITORING WELL CONSTRUCTION DIAGRAM

Exponent

Project Name _____ Contract No. _____
 Well Location _____ Monitoring Well No. _____ Boring No. _____
 Installed By _____ Observed By _____ Installation: Date _____ Time _____
 Method of Installation _____ Total Depth (ft) _____
 Screened Interval _____ Completion Zone - Aquifer _____



Comments _____

Attachment A-3

ASTM Methods

AR302000



Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer¹

This standard is issued under the fixed designation D 3385; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This test method describes a procedure for field measurement of the rate of infiltration of liquid (typically water) into soils using double-ring infiltrometer.

1.2 Soils should be regarded as natural occurring fine or coarse-grained soils or processed materials or mixtures of natural soils and processed materials, or other porous materials, and which are basically insoluble and are in accordance with requirements of 1.5.

1.3 This test method is particularly applicable to relatively uniform fine-grained soils, with an absence of very plastic (fat) clays and gravel-size particles and with moderate to low resistance to ring penetration.

1.4 This test method may be conducted at the ground surface or at given depths in pits, and on bare soil or with vegetation in place, depending on the conditions for which infiltration rates are desired. However, this test method cannot be conducted where the test surface is below the ground water table or perched water table.

1.5 This test method is difficult to use on the resultant data may be unreliable, or both, in very pervious or impervious soils (soils with a hydraulic conductivity greater than about 10^{-2} cm/s or less than about 1×10^{-6} cm/s) or in dry or stiff soils that most likely will fracture when the rings are installed. For soils with hydraulic conductivity less than 1×10^{-6} cm/s refer to Test Method D 5093.

1.6 This test method cannot be used directly to determine the hydraulic conductivity (coefficient of permeability) of the soil (see 5.2).

1.7 The values stated in SI units are to be regarded as the standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

¹ This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.04 on Hydrologic Properties of Soil and Rock.

Current edition approved Sept. 15, 1994. Published November 1994. Originally issued as D 3385 - 75. Last previous edition D 3385 - 88.

D 653 Terminology Relating to Soil, Rock, and Contained Fluids²

D 1452 Practice for Soil Investigation and Sampling by Auger Borings²

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures²

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)²

D 5093 Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer With a Sealed Inner Ring²

3. Terminology

3.1 Definitions:

3.1.1 *incremental infiltration velocity*—the quantity of flow per unit area over an increment of time. It has the same units as the infiltration rate.

3.1.2 *infiltration*—the downward entry of liquid into the soil.

3.1.3 *infiltration rate*—a selected rate, based on measured incremental infiltration velocities, at which liquid can enter the soil under specified conditions, including the presence of an excess of liquid. It has the dimensions of velocity (that is, $\text{cm}^3 \text{cm}^{-2} \text{h}^{-1} = \text{cm h}^{-1}$).

3.1.4 *infiltrometer*—a device for measuring the rate of entry of liquid into a porous body, for example, water into soil.

3.1.5 For definitions of other terms used in this test method, refer to Terminology D 653.

4. Summary of Test Method

4.1 The double-ring infiltrometer method consists of driving two open cylinders, one inside the other, into the ground, partially filling the rings with water or other liquid, and then maintaining the liquid at a constant level. The volume of liquid added to the inner ring, to maintain the liquid level constant is the measure of the volume of liquid that infiltrates the soil. The volume infiltrated during timed intervals is converted to an incremental infiltration velocity, usually expressed in centimetre per hour or inch per hour and plotted versus elapsed time. The maximum-steady state or average incremental infiltration velocity, depending on the purpose/application of the test is equivalent to the infiltration rate.

² Annual Book of ASTM Standards, Vol 04.08.

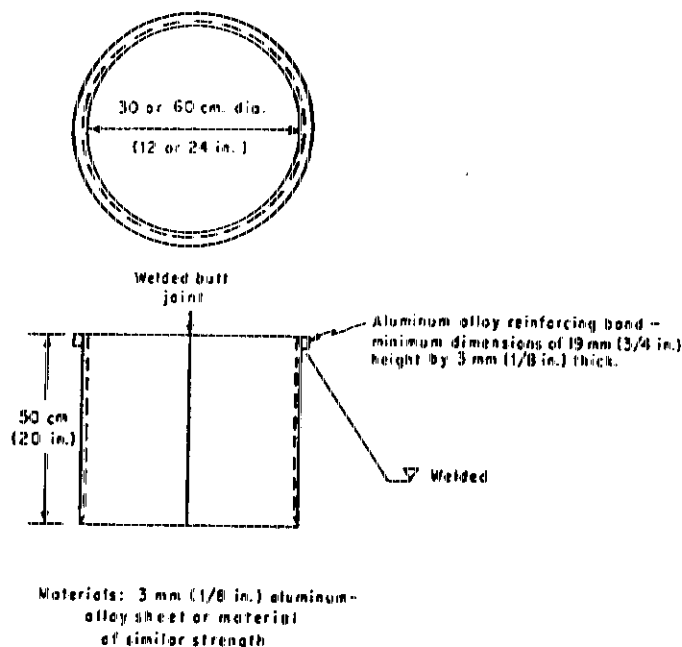


FIG. 1 Infiltrometer Construction

5. Significance and Use

5.1 This test method is useful for field measurement of the infiltration rate of soils. Infiltration rates have application to such studies as liquid waste disposal, evaluation of potential septic-tank disposal fields, leaching and drainage efficiencies, irrigation requirements, water spreading and recharge, and canal or reservoir leakage, among other applications.

5.2 Although the units of infiltration rate and hydraulic conductivity of soils are similar, there is a distinct difference between these two quantities. They cannot be directly related unless the hydraulic boundary conditions are known, such as hydraulic gradient and the extent of lateral flow of water, or can be reliably estimated.

5.3 The purpose of the outer ring is to promote one-dimensional, vertical flow beneath the inner ring.

5.4 Many factors affect the infiltration rate, for example the soil structure, soil layering, condition of the soil surface, degree of saturation of the soil, chemical and physical nature of the soil and of the applied liquid, head of the applied liquid, temperature of the liquid, and diameter and depth of embedment of rings.³ Thus, tests made at the same site are not likely to give identical results and the rate measured by the test method described in this standard is primarily for comparative use.

5.5 Some aspects of the test, such as the length of time the tests should be conducted and the head of liquid to be applied, must depend upon the experience of the user, the purpose for testing, and the kind of information that is sought.

6. Apparatus

6.1 *Infiltrometer Rings*—Cylinders approximately 500

³ Discussion of factors affecting infiltration rate is contained in the following reference: Johnson, A. L., *A Field Method for Measurement of Infiltration*, U.S. Geological Survey Water-Supply Paper 1544-F, 1963, pp. 4-9.

mm (20 in.) high and having diameters of about 300 and 600 mm (12 and 24 in.). Larger cylinders may be used, providing the ratio of the outer to inner cylinders is about two. Cylinders can be made of 3-mm (1/8-in.) hard-alloy, aluminum sheet or other material sufficiently strong to withstand hard driving, with the bottom edge bevelled (see 1). The bevelled edges shall be kept sharp. Stainless steel or strong plastic rings may have to be used when working with corrosive fluids.

6.2 *Driving Caps*—Disks of 13-mm (1/2-in.) thick hard-alloy aluminum with centering pins around the edge, or preferably having a recessed groove about 5 mm (0.2 in.) deep with a width about 1 mm (0.05 in.) wider than the thickness of the ring. The diameters of the disks should be slightly larger than those of the infiltrometer rings.

6.3 *Driving Equipment*—A 5.5-kg (12-lb) maul or sledge and a 600 or 900-mm (2 or 3-ft) length of wood approximately 50 by 100 mm or 100 by 100 mm (2 by 4 in. or 4 by 4 in.), or a jack and reaction of suitable size.

6.4 *Depth Gage*—A hook gage, steel tape or rule, or length of steel or plastic rod pointed on one end, for use in measuring and controlling the depth of liquid (head) in the infiltrometer ring, when either a graduated Mariotte tube or automatic flow control system is not used.

6.5 *Splash Guard*—Several pieces of rubber sheet or burlap 150 mm (6 in.) square.

6.6 *Rule or Tape*—Two-metre (6-ft) steel tape or 300-mm (1-ft) steel rule.

6.7 *Tamp*—Any device that is basically rigid, has a handle not less than 550 mm (22 in.) in length, and has a tamping foot with an area ranging from 650 to 4000 mm² (1 to 6 in.²) and a maximum dimension of 150 mm (6 in.).

6.8 *Shovels*—One long-handled shovel and one trench-spade.

6.9 *Liquid Containers*:

6.9.1 One 200-L (55-gal) barrel for the main liquid supply, along with a length of rubber hose to siphon liquid from the barrel to fill the calibrated head tanks (see 6.9.3).

6.9.2 A 13-L (12-qt) pail for initial filling of the infiltrometers.

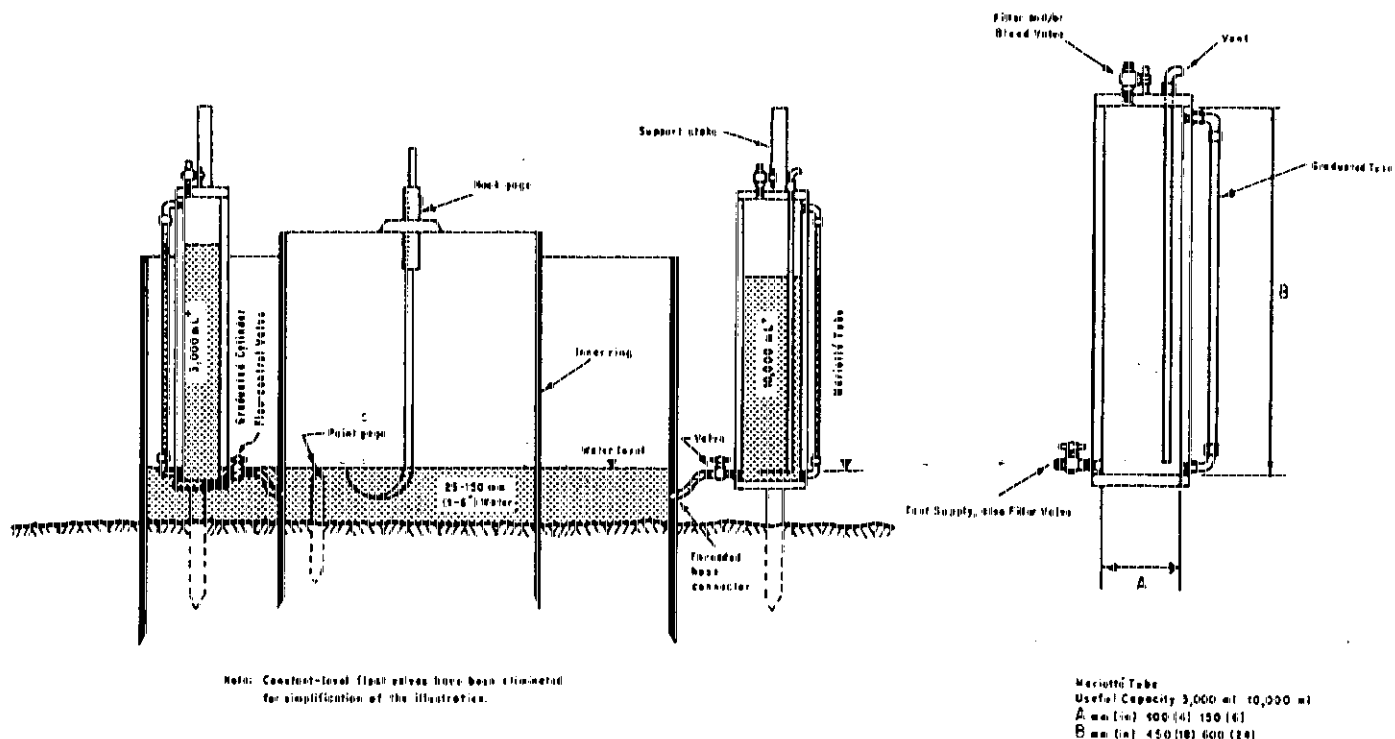
6.9.3 Two calibrated head tanks for measurement of liquid flow during the test. These may be either graduated cylinders or Mariotte tubes having a minimum volume capacity of about 3000 mL (see Notes 1 and 2 and Fig. 2).

NOTE 1—It is useful to have one head tank with a capacity of three times that of the other because the area of the annular space between the rings is about three times that of the inner ring.

NOTE 2—In many cases, the volume capacity of these calibrated head tanks must be significantly larger than 3000 mL, especially if the test has to continue overnight. Capacities of about 50 L (13 gal) would not be uncommon.

6.10 *Liquid Supply*—Water, or preferably, liquid of the same quality and temperature as that involved in the problem being examined. The liquid used must be chemically compatible with the infiltrometer rings and other equipment used to contain the liquid.

NOTE 3—To obtain maximum infiltration rates, the liquid should be free from suspended solids and the temperature of the liquid should be higher than the soil temperature. This will tend to avoid reduction of infiltration from blockage of voids by particles or gases coming out of solution.



NOTE—Constant-level float valves have been eliminated for simplification of the illustration

FIG. 2 Ring Installation and Mariotte Tube Details

6.11 *Watch or Stopwatch*—A stopwatch would only be required for high infiltration rates.

6.12 *Level*—A carpenter's level or bull's-eye (round) level.

6.13 *Thermometer*—With accuracy of 0.5°C and capable of measuring ground temperature.

6.14 *Rubber Hammer (mallet)*.

6.15 *pH Paper*, in 0.5 increments.

6.16 *Recording Materials*—Record books and graph paper, or special forms with graph section (see Fig. 3 and Fig. 4).

6.17 *Hand Auger*—Orchard-type (barrel-type) auger with 75-mm (3-in.) diameter, 225-mm (9-in.) long barrel and a rubber-headed tire hammer for knocking sample out of the auger. This apparatus is optional.

6.18 *Float Valves*—Two constant level float valves (carburetors or bob-float types) with support stands. This apparatus is optional.

6.19 *Covers and Dummy Tests Set-Up*—For long-term tests in which evaporation of fluid from the infiltration rings and unsealed reservoirs can occur (see 8.2.1).

7. Calibration

7.1 Rings:

7.1.1 Determine the area of each ring and the annular space between rings before initial use and before reuse after anything has occurred, including repairs, which may affect the test results significantly.

7.1.2 Determine the area using a measuring technique that will provide an overall accuracy of 1 %.

7.1.3 The area of the annular space between rings is equal to the internal area of the 600-mm (24-in.) ring minus the external area of the 300-mm (12-in.) ring.

7.2 *Liquid Containers*—For each graduated cylinder or graduated Mariotte tube, establish the relationship between the change in elevation of liquid (fluid) level and change in volume of fluid. This relationship shall have an overall accuracy of 1 %.

8. Procedure

8.1 Test Site:

8.1.1 Establish the soil strata to be tested from the soil profile determined by the classification of soil samples from an adjacent auger hole.

NOTE 4—For the test results to be valid for soils below the test zone, the soil directly below the test zone must have equal or greater flow rates than the test zone.

8.1.2 The test requires an area of approximately 3 by 3 m (10 by 10 ft) accessible by a truck.

8.1.3 The test site should be nearly level, or a level surface should be prepared.

8.1.4 The test may be set up in a pit if infiltration rates are desired at depth rather than at the surface.

8.2 Technical Precautions:

8.2.1 For long-term tests, avoid unattended sites where interference with test equipment is possible, such as sites near children or in pastures with livestock. Also, evaporation of fluid from the rings and unsealed reservoirs can lead to errors in the measured infiltration rate. Therefore, in such tests, completely cover the top of the rings and unsealed reservoirs with a relatively airtight material, but vented to the atmosphere through a small hole or tube. In addition, make measurements to verify that the rate of evaporation in a similar test configuration (without any infiltration into the

Project Identification A/R.T.S. Constants Area (cm²) 707 4.0 1 78.54
 Test Location EDAHQ - Lost River Alluvium Inner Ring : 707 4.0 1 78.54
 Liquid Used River water pH = 8.0 Annular Space: 2106 4.1 2 176.70
 Tested by JJA CAUS Liquid level maintained using: ☐ Flow valve; ☐ Float valve; ☒ Mariotte tube
 Depth to water table: 5.2 (m) Penetration of rings: Inner: 7.5 (cm); Outer: 17.5 (cm)

Trial No.	Date	Time	Elapsed Time (Total)	Flow Readings		Annular Space Reading	Flow	Liquid Temp	Incr. In Silt Rate		Ground temp. = 14.5° at depth of 30 (cm)	Remarks: Weather Conditions, etc.
				Inner Ring Reading	Flow				Inner	Annular		
1	S	10/14	10:00	15	3.0	114	2.2	389	15	0.64	0.74	Cloudy, slight wind
	E	"	10:15	(15)	4.45		4.4					
2	S	"	10:15	15	4.45	212	4.4	795	15	1.2	1.5	
	E	"	10:30	(30)	7.15		8.9					
3	S	"	10:30	15	7.15	263	8.9	848	15	1.5	1.6	
	E	"	10:45	(45)	10.5		13.7					
4	S	"	10:45	15	10.5	306	13.7	945	15	1.7	1.8	
	E	"	11:00	(60)	14.4		19.05		15.5			
5	S	"	11:00	30	14.4	758	19.05	2324	15.5	2.1	2.2	
	E	"	11:30	(90)	24.05		32.2		16			
6	S	"	11:30	30	24.05	848	32.2	2580	16	2.4	2.45	
	E	"	12:00	(120)	34.85		46.8		16.5			
7	S	"	12:10	60	3.5	1944	2.2	5902	16.5	2.75	2.8	Resilled tubes
	E	"	13:10	(180)	28.25		35.6		17			
8	S	"	13:20	60	2.4	1877	3.2	5690	17.5	2.65	2.7	" "
	E	"	14:20	(240)	26.3		35.4		"			
9	S	"	14:30	60	4.3	1696	4.7	5054	17.5	2.4	2.4	" "
	E	"	15:30	(300)	25.9		33.3		18			
10	S	"	15:40	60	2.2	1586	4.5	4842	18	2.2	2.3	" "
	E	"	16:40	(360)	22.4		31.9		11			Cloudy, slight wind

FIG. 3 Data Form for Infiltration Test with Sample Data

soil) is less than 20 % of the infiltration rate being measured.

8.2.2 Make provisions to protect the test apparatus and fluid from direct sunlight and temperature variations that are large enough to affect the slow measurements significantly, especially for test durations greater than a few hours or those using a Mariotte tube. The expansion or contraction of the air in the Mariotte tube above the water due to temperature changes may cause changes in the rate of flow of the liquid from the tube which will result in a fluctuating water level in the infiltrometer rings.

8.3 Driving Infiltration Rings with a Sledge:

NOTE 5—Driving rings with a jack is preferred; see 8.4.

8.3.1 Place the driving cap on the outer ring and center it thereon. Place the wood block (see 6.3) on the driving cap.

8.3.2 Drive the outer ring into the soil with blows of a heavy sledge on the wood block to a depth that will (a) prevent the test fluid from leaking to the ground surface surrounding the ring, and (b) be deeper than the depth to which the inner ring will be driven. A depth of about 150 mm (6 in.) is usually adequate. Use blows of medium force to prevent fracturing of the soil surface. Move the wood

block around the edge of the driving cap every one or two blows so that the ring will penetrate the soil uniformly. A second person standing on the wood block and driving cap will usually facilitate driving the ring, and reduce vibrations and disturbance.

8.3.3 Center the smaller ring inside the larger ring and drive to a depth that will prevent leakage of the test fluid to the ground surface surrounding the ring, using the same technique as in 8.3.2. A depth of between about 50 and 100 mm (2 and 4 in.) is usually adequate.

8.4 Driving Infiltration Rings with Jacks:

8.4.1 Use a heavy jack under the back end of a truck to drive rings as an alternative to the sledge method (see 8.3).

8.4.2 Center the wood block across the driving cap of the ring. Center a jack on the wood block. Place the top of the jack and the assembled items vertically under the previously positioned end of a truck body and apply force to the ring by means of the jack and truck reaction. Also, tamp near the edges or near the center of the ring with the rubber mallet, as slight tamping and vibrations will reduce hang-ups and tilting of the ring.

8.4.3 Add additional weight to the truck if needed to

Project Identification NRTS Prepared by ISA Date of Test: Start 10/14/84; Finish 10/14/84
 Project Location EDMHO - East River Alluvium Remarks: Ground temp. = 14°C
 Liquid Used: River water pH = 8.0; Ave. Temp. = 16.0 ± 1 (°C)

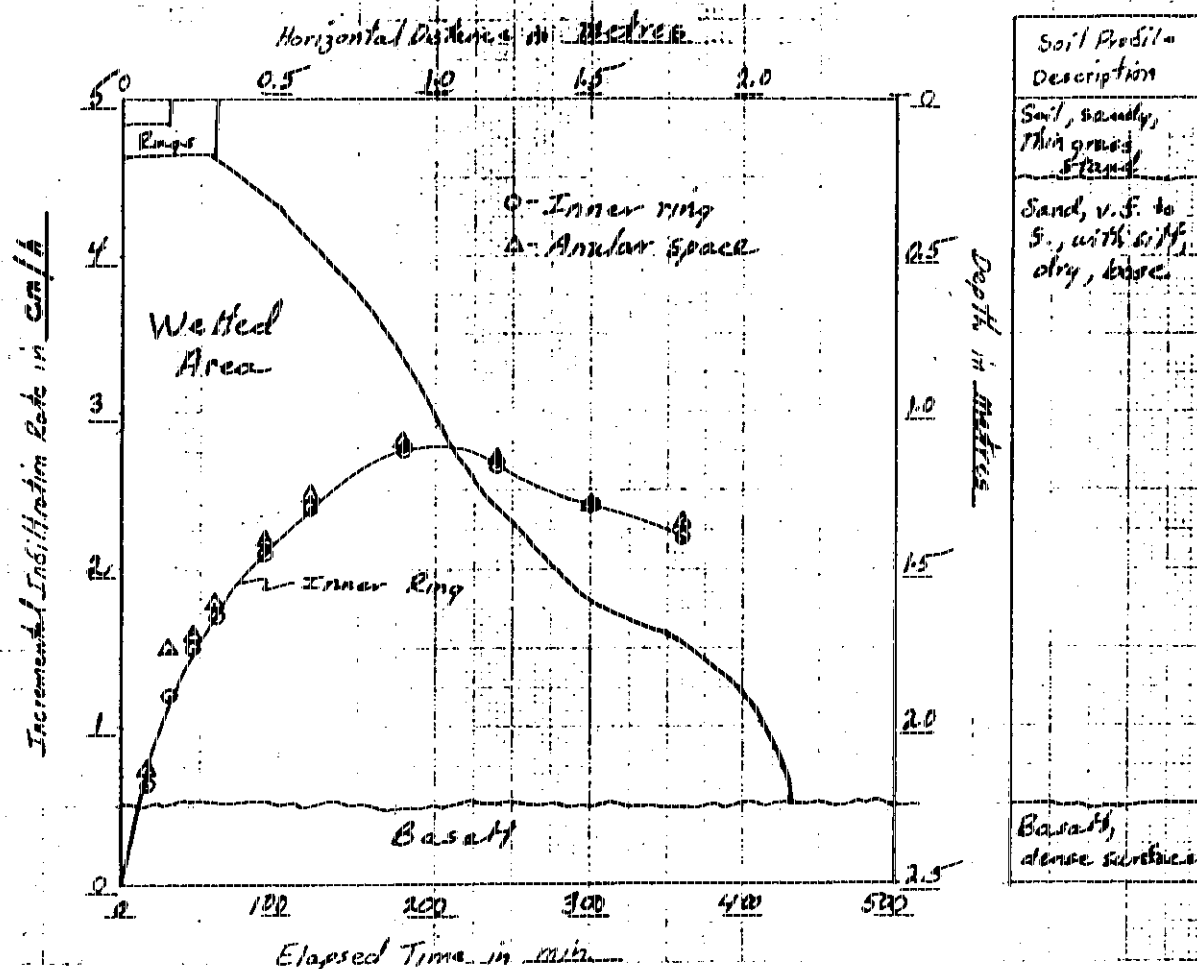


FIG. 4 Report Form for Infiltration Test With Sample Data

develop sufficient force to drive the ring.

8.4.4 Check the rings with the level, correcting the attitude of the rings to be vertical, as needed.

8.5 Tamping Disturbed Soil:

8.5.1 If the surface of the soil surrounding the wall of the ring(s) is excessively disturbed (signs of extensive cracking, excessive heave, and the like), reset the ring(s) using a technique that will minimize such disturbance.

8.5.2 If the surface of the soil surrounding the wall of the ring(s) is only slightly disturbed, tamp the disturbed soil adjacent to the inside and outside wall of the ring(s) until the soil is as firm as it was prior to disturbance.

8.6 Maintaining Liquid Level:

8.6.1 There are basically three ways to maintain a constant head (liquid level) within the inner ring and annular space between the two rings: manually controlling the flow of liquid, the use of constant-level float valves, or the use of a Mariotte tube.

8.6.2 When manually controlling the flow of liquid, a depth gage is required to assist the investigator visually in

maintaining a constant head. Use a depth gage such as a steel tape or rule for soils having a relatively high permeability; for soils having a relatively low permeability use a hook gage or simple point gage.

8.6.3 Install the depth gages, constant-level valves, or Mariotte tubes as shown in Fig. 2, and in such a manner that the reference head will be at least 25 mm (1 in.) and not greater than 150 mm (6 in.). Select the head on the basis of the permeability of the soil, the higher heads being required for lower permeability soils. Locate the depth gages near the center of the center ring and midway between the two rings.

8.6.4 Cover the soil surface within the center ring and between the two rings with splash guards (150-mm (6-in.) square pieces of burlap or rubber sheet) to prevent erosion of the soil when the initial liquid supply is poured into the rings.

8.6.5 Use a pail to fill both rings with liquid to the same desired depth in each ring. Do not record this initial volume of liquid. Remove the splash guards.

8.6.6 Start flow of fluid from the graduated cylinders or

Mariotte tubes. As soon as the fluid level becomes basically constant, determine the fluid depth in the inner ring and in the annular space to the nearest 2 mm ($1/16$ in.) using a ruler or tape measure. Record these depths. If the depths between the inner ring and annular space varies more than 5 mm ($1/4$ in.), raise the depth gage, constant-level float valve, or Mariotte tube having the shallowest depth.

8.6.7 Maintain the liquid level at the selected head in both the inner ring and annular space between rings as near as possible throughout the test, to prevent flow of fluid from one ring to the other.

Note 6—This most likely will require either a continuing adjustment of the flow control valve on the graduated cylinder, or the use of constant-level float valves. A rapid change in temperature may eliminate use of the Mariotte tube.

8.7 Measurements:

8.7.1 Record the ground temperature at a depth of about 300 mm (12 in.), or at the mid-depth of the test zone.

8.7.2 Determine and record the volume of liquid that is added to maintain a constant head in the inner ring and annular space during each timing interval by measuring the change in elevation of liquid level in the appropriate graduated cylinder or Mariotte tube. Also, record the temperature of the liquid within the inner ring.

8.7.3 For average soils, record the volume of liquid used at intervals of 15 min for the first hour, 30 min for the second hour, and 60 min during the remainder of a period of at least 6 h, or until after a relatively constant rate is obtained.

8.7.4 The appropriate schedule of readings may be determined only through experience. For high-permeability materials, readings may be more frequent, while for low-permeability materials, the reading interval may be 24 h or more. In any event, the volume of liquid used in any one reading interval should not be less than approximately 25 cm³.

8.7.5 Place the driving cap or some other covering over the rings during the intervals between liquid measurements to minimize evaporation (see 8.2.1).

8.7.6 Upon completion of the test, remove the rings from the soil, assisted by light hammering on the sides with a rubber hammer.

9. Calculations

9.1 Convert the volume of liquid used during each measured time interval into an incremental infiltration velocity for both the inner ring and annular space using the following equations:

9.1.1 For the inner ring calculate as follows:

$$V_{IR} = \Delta V_{IR} / (A_{IR} \cdot \Delta t)$$

where:

- V_{IR} = inner ring incremental infiltration velocity, cm/h,
 ΔV_{IR} = volume of liquid used during time interval to maintain constant head in the inner ring, cm³,
 A_{IR} = internal area of inner ring, cm², and

Δt = time interval, h.

9.1.2 For the annular space between rings calculate follows:

$$V_A = \Delta V_A / (A_A \cdot \Delta t)$$

where:

V_A = annular space incremental infiltration velocity, cm/h,

ΔV_A = volume of liquid used during time interval to maintain constant head in the annular space between the rings, cm³, and

A_A = area of annular space between the rings, cm².

10. Report

10.1 Report the following information in the report, field records, or both:

10.1.1 Location of test site.

10.1.2 Dates of test, start and finish.

10.1.3 Weather conditions, start to finish.

10.1.4 Name(s) of technician(s).

10.1.5 Description of test site, including boring profile, see 10.1.11.

10.1.6 Type of liquid used in the test, along with the liquid's pH. If available, a full analysis of the liquid also should be recorded.

10.1.7 Areas of rings and the annular space between rings.

10.1.8 Volume constants for graduated cylinders or Mariotte tubes.

10.1.9 Depth of liquid in inner ring and annular space.

10.1.10 Record of ground and liquid temperatures, incremental volume measurements, and incremental infiltration velocities (inner ring and annular space) versus elapsed time. The rate of the inner ring should be the value used if the rates for inner ring and annular space differ. The difference in rates is due to divergent flow.

10.1.11 If available, depth to the water table and a description of the soils found between the rings and the water table, or to a depth of about 1 m (3 ft).

10.1.12 A plot of the incremental infiltration rate versus total elapsed time (see Fig. 4).

10.2 An example field records form is given in Fig. 3.

10.3 See Appendix X1 for information on the determination of the moisture pattern.

11. Precision and Bias

11.1 No statement on precision and bias can be made due to the variability in soils tested and in the types of liquids that might be used in this test method. Because of the many factors related to the soils, as well as the liquids that may affect the results, the recorded infiltration rate should be considered only as an index value.

12. Keywords

12.1 coefficient of permeability; hydraulic conductivity; infiltration rate; infiltrometer; in-situ testing; Mariotte tube

APPENDIX

(Nonmandatory Information)

X1. DETERMINATION OF MOISTURE PATTERN

X1.1 Although not considered a required part of the test method, the determination of the moisture pattern in the moistened soil beneath the infiltration rings commonly provides information useful in interpreting the movement of liquid through the soil profile. For example, horizontal liquid movement may be caused by lower-permeability layers and will be identified by a lateral spreading of the wetted zone. Thus, the exploration of the soil moisture pattern below an infiltration test in an unfamiliar area may identify subsurface conditions that may have affected the test and later applications of the data.

X1.2 If the investigator wishes to make such a study, dig a trench so that one wall of the trench passes along the center

line of the former position of the rings. Orient the trench so that the other wall is illuminated by the sun, if the day is sunny. If feasible, dig the trench large enough to include all of the newly moistened area. Collect samples from the shaded wall of the trench for determination of water content. If preferred, an auger, such as the orchard barrel type, may be used to determine the approximate outline of the moistened area below the rings and to collect samples for water content.

X1.3 Plot the visibly moistened area on graph paper or on the cross-section part of the report form (see Fig. 4). If samples were collected and water contents were determined, contours of water content also can be plotted on the graph.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.



Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)¹

This standard is issued under the fixed designation D 2488; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This practice covers procedures for the description of soils for engineering purposes.

1.2 This practice also describes a procedure for identifying soils, at the option of the user, based on the classification system described in Test Method D 2487. The identification is based on visual examination and manual tests. It must be clearly stated in reporting an identification that it is based on visual-manual procedures.

1.2.1 When precise classification of soils for engineering purposes is required, the procedures prescribed in Test Method D 2487 shall be used.

1.2.2 In this practice, the identification portion assigning a group symbol and name is limited to soil particles smaller than 3 in. (75 mm).

1.2.3 The identification portion of this practice is limited to naturally occurring soils (disturbed and undisturbed).

NOTE 1—This practice may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. (See Appendix X2).

1.3 The descriptive information in this practice may be used with other soil classification systems or for materials other than naturally occurring soils.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific precautionary statements see Section 8.*

1.5 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 ASTM Standards:

- D 653 Terminology Relating to Soil, Rock, and Contained Fluids²
- D 1452 Practice for Soil Investigation and Sampling by Auger Borings²
- D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils²

¹ This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

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² Annual Book of ASTM Standards, Vol 04.08.

D 1587 Practice for Thin-Walled Tube Sampling of Soil
D 2113 Practice for Diamond Core Drilling for Soil Investigation²

D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)²

D 4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)²

3. Terminology

3.1 Definitions:

3.1.1 Except as listed below, all definitions are in accordance with Terminology D 653.

NOTE 2—For particles retained on a 3-in. (75-mm) US standard sieve, the following definitions are suggested:

Cobbles—particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) sieve, and

Boulders—particles of rock that will not pass a 12-in. (300-mm) square opening.

3.1.1.2 **clay**—soil passing a No. 200 (75- μ m) sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air-dry. For classification, a clay is fine-grained soil, or the fine-grained portion of a soil, with plasticity index equal to or greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line (see Fig. 3 of Test Method D 2487).

3.1.1.3 **gravel**—particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

coarse—passes a 3-in. (75-mm) sieve and is retained on 3/4-in. (19-mm) sieve.

fine—passes a 3/4-in. (19-mm) sieve and is retained on No. 4 (4.75-mm) sieve.

3.1.1.4 **organic clay**—a clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay, except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

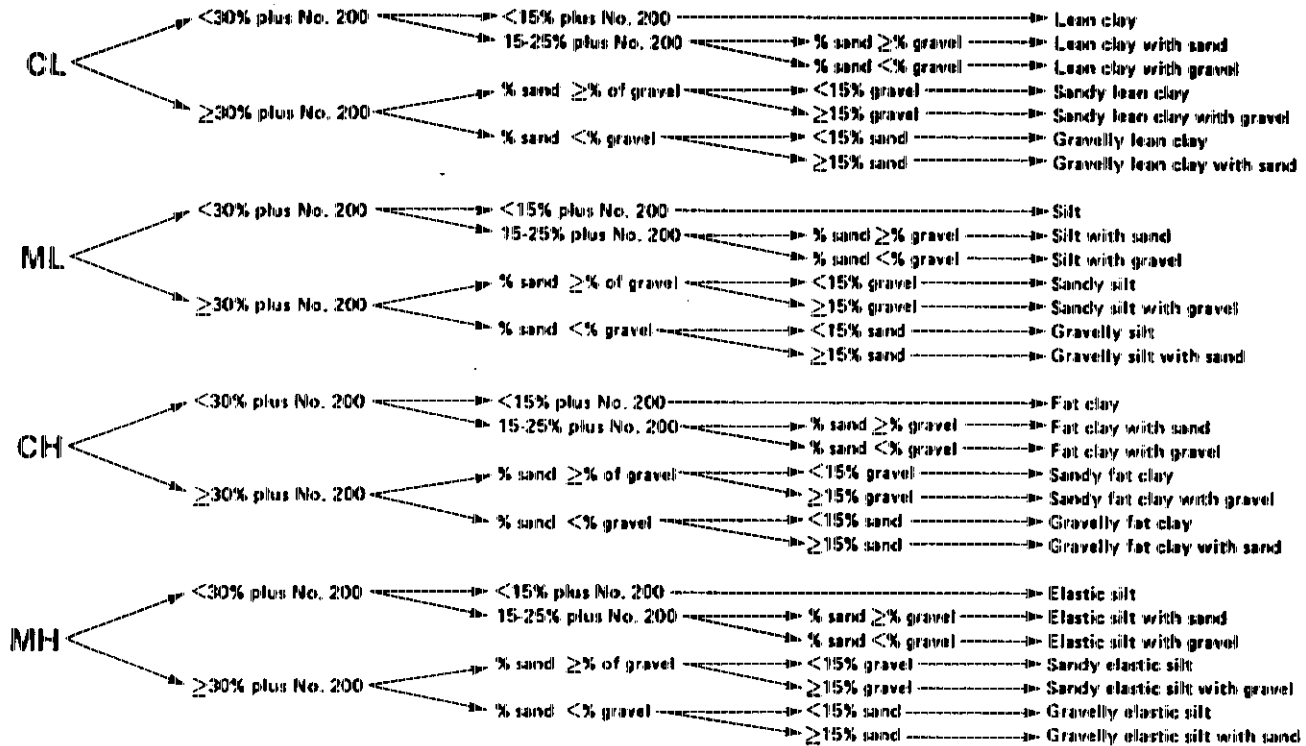
3.1.1.5 **organic silt**—a silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.1.6 **peat**—a soil composed primarily of vegetable tissue in various stages of decomposition usually with an organic odor, a dark brown to black color, a spongy consistency, and texture ranging from fibrous to amorphous.

3.1.1.7 **sand**—particles of rock that will pass a No.

GROUP SYMBOL

GROUP NAME



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1a Flow Chart for Identifying Inorganic Fine-Grained Soil (50 % or more fines)

(4.75-mm) sieve and be retained on a No. 200 (75-μm) sieve with the following subdivisions:

coarse—passes a No. 4 (4.75-mm) sieve and is retained on a No. 10 (2.00-mm) sieve.

medium—passes a No. 10 (2.00-mm) sieve and is retained on a No. 40 (425-μm) sieve.

fine—passes a No. 40 (425-μm) sieve and is retained on a No. 200 (75-μm) sieve.

3.1.1.8 *silt*—soil passing a No. 200 (75-μm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less than 4, or the plot of plasticity index versus liquid limit falls below the “A” line (see Fig. 3 of Test Method D 2487).

4. Summary of Practice

4.1 Using visual examination and simple manual tests, this practice gives standardized criteria and procedures for describing and identifying soils.

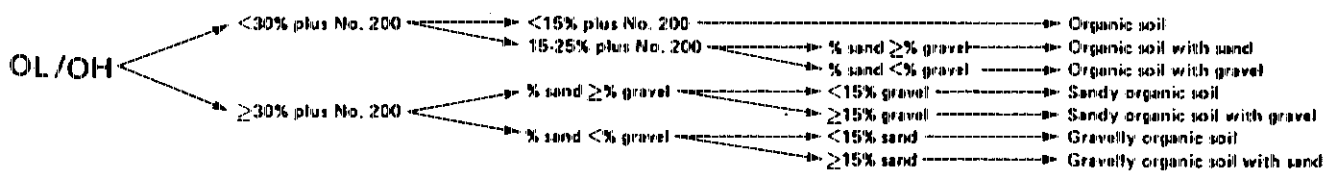
4.2 The soil can be given an identification by assigning a group symbol(s) and name. The flow charts, Figs. 1a and 1b for fine-grained soils, and Fig. 2, for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name. If the soil has properties which do not distinctly place it into a specific group, borderline symbols may be used, see Appendix X3.

NOTE 3—It is suggested that a distinction be made between *dual symbols* and *borderline symbols*.

Dual Symbol—A dual symbol is two symbols separated by a hyphen, for example, GP-GM, SW-SC, CL-ML used to indicate that the soil has been identified as having the properties of a classification in accordance with Test Method D 2487 where two symbols are required. Two symbols are required when the soil has between 5 and 12 % fines or

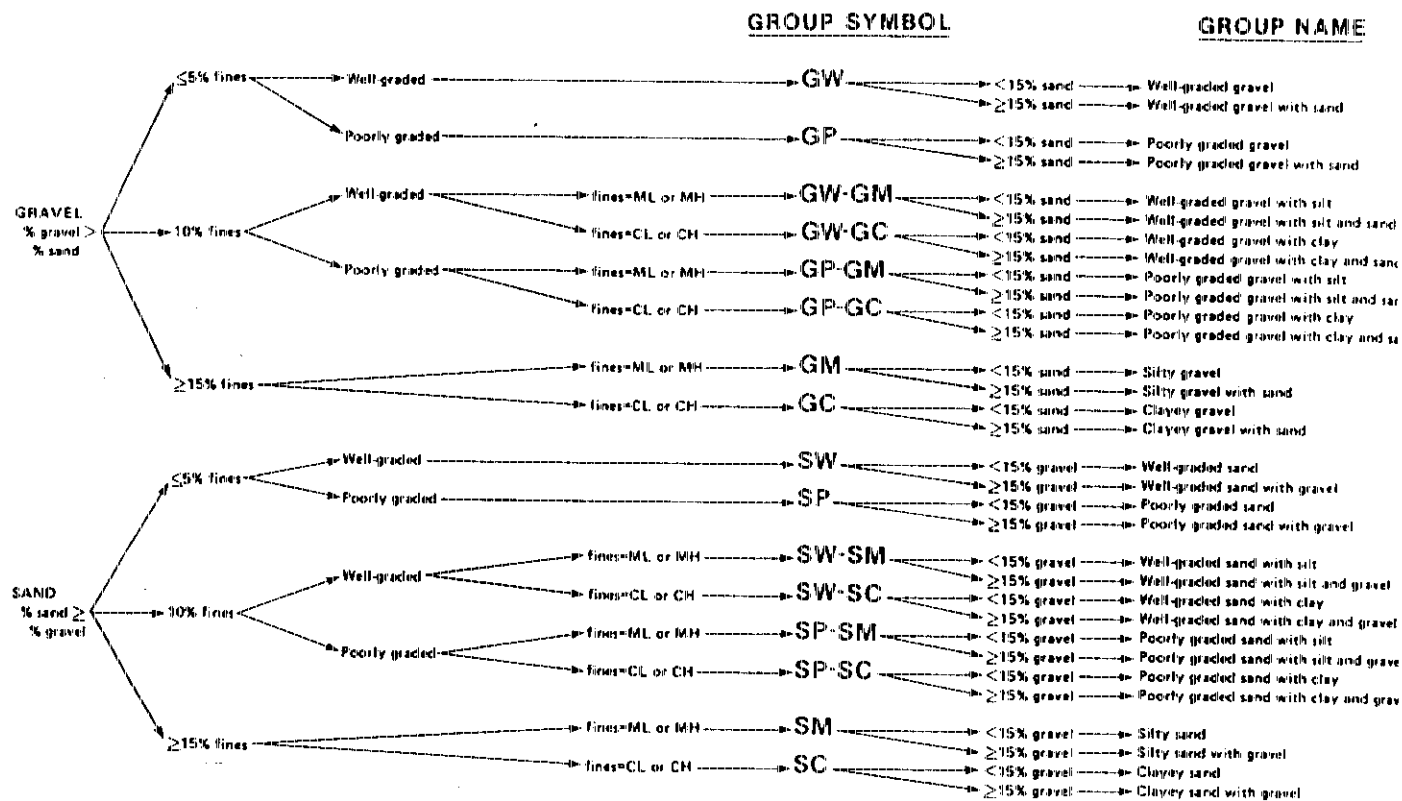
GROUP SYMBOL

GROUP NAME



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1b Flow Chart for Identifying Organic Fine-Grained Soil (50 % or more fines)



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 2 Flow Chart for Identifying Coarse-Grained Soils (less than 50 % fines)

when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

Borderline Symbol—A borderline symbol is two symbols separated by a slash, for example, CL/CH, GM/SM, CL/ML. A borderline symbol should be used to indicate that the soil has been identified as having properties that do not distinctly place the soil into a specific group (see Appendix X3).

5. Significance and Use

5.1 The descriptive information required in this practice can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

5.2 The descriptive information required in this practice should be used to supplement the classification of a soil as determined by Test Method D 2487.

5.3 This practice may be used in identifying soils using the classification group symbols and names as prescribed in Test Method D 2487. Since the names and symbols used in this practice to identify the soils are the same as those used in Test Method D 2487, it shall be clearly stated in reports and all other appropriate documents, that the classification symbol and name are based on visual-manual procedures.

5.4 This practice is to be used not only for identification of soils in the field, but also in the office, laboratory, or wherever soil samples are inspected and described.

5.5 This practice has particular value in grouping similar soil samples so that only a minimum number of laboratory tests need be run for positive soil classification.

NOTE 4—The ability to describe and identify soils correctly is learned more readily under the guidance of experienced personnel, but it may also be acquired systematically by comparing numerical laboratory test

results for typical soils of each type with their visual and manual characteristics.

5.6 When describing and identifying soil samples from a given boring, test pit, or group of borings or pits, it is not necessary to follow all of the procedures in this practice for every sample. Soils which appear to be similar can be grouped together; one sample completely described and identified with the others referred to as similar based on performing only a few of the descriptive and identification procedures described in this practice.

5.7 This practice may be used in combination with Practice D 4083 when working with frozen soils.

6. Apparatus

6.1 Required Apparatus:

6.1.1 Pocket Knife or Small Spatula.

6.2 Useful Auxiliary Apparatus:

6.2.1 Small Test Tube and Stopper (or jar with a lid).

6.2.2 Small Hand Lens.

7. Reagents

7.1 **Purity of Water**—Unless otherwise indicated, references to water shall be understood to mean water from a city water supply or natural source, including non-potable water.

7.2 **Hydrochloric Acid**—A small bottle of dilute hydrochloric acid, HCl, one part HCl (10 N) to three parts water (This reagent is optional for use with this practice). See Section 8.

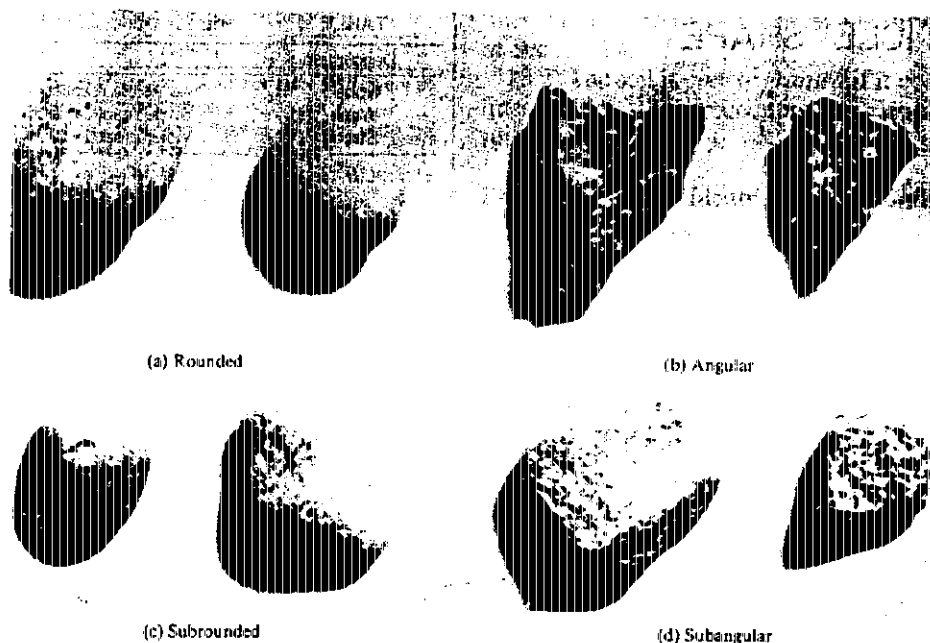


FIG. 3 Typical Angularity of Bulky Grains

8. Safety Precautions

8.1 When preparing the dilute HCl solution of one part concentrated hydrochloric acid (10 N) to three parts of distilled water, slowly add acid into water following necessary safety precautions. Handle with caution and store safely. If solution comes into contact with the skin, rinse thoroughly with water.

8.2 Caution—Do not add water to acid.

9. Sampling

9.1 The sample shall be considered to be representative of the stratum from which it was obtained by an appropriate, accepted, or standard procedure.

NOTE 5—Preferably, the sampling procedure should be identified as having been conducted in accordance with Practices D 1452, D 1587, or D 2113, or Method D 1586.

9.2 The sample shall be carefully identified as to origin.

NOTE 6—Remarks as to the origin may take the form of a boring number and sample number in conjunction with a job number, a geologic stratum, a pedologic horizon or a location description with respect to a permanent monument, a grid system or a station number and offset with respect to a stated centerline and a depth or elevation.

9.3 For accurate description and identification, the minimum amount of the specimen to be examined shall be in

accordance with the following schedule:

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, Dry Weight
4.75 mm (No. 4)	100 g (0.25 lb)
9.5 mm (3/8 in.)	200 g (0.5 lb)
19.0 mm (3/4 in.)	1.0 kg (2.2 lb)
38.1 mm (1 1/2 in.)	8.0 kg (18 lb)
75.0 mm (3 in.)	60.0 kg (132 lb)

NOTE 7—If random isolated particles are encountered that are significantly larger than the particles in the soil matrix, the soil matrix can be accurately described and identified in accordance with the preceding schedule.

9.4 If the field sample or specimen being examined is smaller than the minimum recommended amount, the report shall include an appropriate remark.

10. Descriptive Information for Soils

10.1 *Angularity*—Describe the angularity of the sand (coarse sizes only), gravel, cobbles, and boulders, as angular, subangular, subrounded, or rounded in accordance with the criteria in Table 1 and Fig. 3. A range of angularity may be stated, such as: subrounded to rounded.

10.2 *Shape*—Describe the shape of the gravel, cobbles, and boulders as flat, elongated, or flat and elongated if they meet the criteria in Table 2 and Fig. 4. Otherwise, do not mention the shape. Indicate the fraction of the particles that have the shape, such as: one-third of the gravel particles are flat.

10.3 *Color*—Describe the color. Color is an important property in identifying organic soils, and within a given

TABLE 1 Criteria for Describing Angularity of Coarse-Grained Particles (see Fig. 3)

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

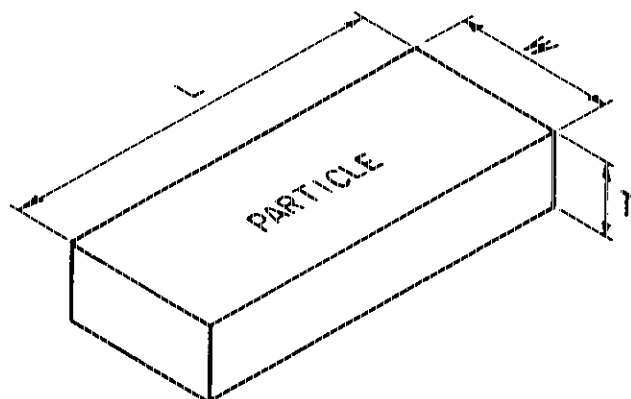
TABLE 2 Criteria for Describing Particle Shape (see Fig. 4)

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

PARTICLE SHAPE

W = WIDTH
T = THICKNESS
L = LENGTH



FLAT: $W/T > 3$
ELONGATED: $L/W > 3$
FLAT AND ELONGATED:
-meets both criteria

FIG. 4 Criteria for Particle Shape

TABLE 3 Criteria for Describing Moisture Condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

locality it may also be useful in identifying materials of similar geologic origin. If the sample contains layers or patches of varying colors, this shall be noted and all representative colors shall be described. The color shall be described for moist samples. If the color represents a dry condition, this shall be stated in the report.

10.4 *Odor*—Describe the odor if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples, but if the samples are dried, the odor may often be revived by heating a moistened sample. If the odor is unusual (petroleum product, chemical, and the like), it shall be described.

10.5 *Moisture Condition*—Describe the moisture condition as dry, moist, or wet, in accordance with the criteria in Table 3.

10.6 *HCl Reaction*—Describe the reaction with HCl as none, weak, or strong, in accordance with the criteria in Table 4. Since calcium carbonate is a common cementing agent, a report of its presence on the basis of the reaction with dilute hydrochloric acid is important.

TABLE 4 Criteria for Describing the Reaction With HCl

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

TABLE 5 Criteria for Describing Consistency

Description	Criteria
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about 1/4 in. (6 mm)
Hard	Thumb will not indent soil but readily indented with thumb
Very hard	Thumbnail will not indent soil

10.7 *Consistency*—For intact fine-grained soil, describe the consistency as very soft, soft, firm, hard, or very hard accordance with the criteria in Table 5. This observation is inappropriate for soils with significant amounts of gravel.

10.8 *Cementation*—Describe the cementation of intact coarse-grained soils as weak, moderate, or strong, in accordance with the criteria in Table 6.

10.9 *Structure*—Describe the structure of intact soils accordance with the criteria in Table 7.

10.10 *Range of Particle Sizes*—For gravel and sand components, describe the range of particle sizes within a component as defined in 3.1.2 and 3.1.6. For example, about 20 % fine to coarse gravel, about 40 % fine to coarse sand.

10.11 *Maximum Particle Size*—Describe the maximum particle size found in the sample in accordance with the following information:

10.11.1 *Sand Size*—If the maximum particle size is sand size, describe as fine, medium, or coarse as defined in 3.1.6. For example: maximum particle size, medium sand.

10.11.2 *Gravel Size*—If the maximum particle size is gravel size, describe the maximum particle size as the smallest sieve opening that the particle will pass. For example, maximum particle size, 1 1/2 in. (will pass a 1 1/2-in. square opening but not a 3/4-in. square opening).

10.11.3 *Cobble or Boulder Size*—If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle. For example: maximum dimension, 18 in. (450 mm).

10.12 *Hardness*—Describe the hardness of coarse sand and larger particles as hard, or state what happens when the particles are hit by a hammer, for example, gravel-size particles fracture with considerable hammer blow, sand gravel-size particles crumble with hammer blow. "Hard" means particles do not crack, fracture, or crumble under hammer blow.

10.13 Additional comments shall be noted, such as the presence of roots or root holes, difficulty in drilling, augering hole, caving of trench or hole, or the presence of mica.

10.14 A local or commercial name or a geologic interpretation.

TABLE 6 Criteria for Describing Cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

TABLE 7 Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

tation of the soil, or both, may be added if identified as such.

10.15 A classification or identification of the soil in accordance with other classification systems may be added if identified as such.

11. Identification of Peat

11.1 A sample composed primarily of vegetable tissue in various stages of decomposition that has a fibrous to amorphous texture, usually a dark brown to black color, and an organic odor, shall be designated as a highly organic soil and shall be identified as peat, PT, and not subjected to the identification procedures described hereafter.

12. Preparation for Identification

12.1 The soil identification portion of this practice is based on the portion of the soil sample that will pass a 3-in. (75-mm) sieve. The larger than 3-in. (75-mm) particles must be removed, manually, for a loose sample, or mentally, for an intact sample before classifying the soil.

12.2 Estimate and note the percentage of cobbles and the percentage of boulders. Performed visually, these estimates will be on the basis of volume percentage.

NOTE 8—Since the percentages of the particle-size distribution in Test Method D 2487 are by dry weight, and the estimates of percentages for gravel, sand, and fines in this practice are by dry weight, it is recommended that the report state that the percentages of cobbles and boulders are by volume.

12.3 Of the fraction of the soil smaller than 3 in. (75 mm), estimate and note the percentage, by dry weight, of the gravel, sand, and fines (see Appendix X4 for suggested procedures).

NOTE 9—Since the particle-size components appear visually on the basis of volume, considerable experience is required to estimate the percentages on the basis of dry weight. Frequent comparisons with laboratory particle-size analyses should be made.

12.3.1 The percentages shall be estimated to the closest 5 %. The percentages of gravel, sand, and fines must add up to 100 %.

12.3.2 If one of the components is present but not in sufficient quantity to be considered 5 % of the smaller than 3-in. (75-mm) portion, indicate its presence by the term *trace*, for example, trace of fines. A trace is not to be considered in the total of 100 % for the components.

13. Preliminary Identification

13.1 The soil is *fine grained* if it contains 50 % or more

fines. Follow the procedures for identifying fine-grained soils of Section 14.

13.2 The soil is *coarse grained* if it contains less than 50 % fines. Follow the procedures for identifying coarse-grained soils of Section 15.

14. Procedure for Identifying Fine-Grained Soils

14.1 Select a representative sample of the material for examination. Remove particles larger than the No. 40 sieve (medium sand and larger) until a specimen equivalent to about a handful of material is available. Use this specimen for performing the dry strength, dilatancy, and toughness tests.

14.2 Dry Strength:

14.2.1 From the specimen, select enough material to mold into a ball about 1 in. (25 mm) in diameter. Mold the material until it has the consistency of putty, adding water if necessary.

14.2.2 From the molded material, make at least three test specimens. A test specimen shall be a ball of material about ½ in. (12 mm) in diameter. Allow the test specimens to dry in air, or sun, or by artificial means, as long as the temperature does not exceed 60°C.

14.2.3 If the test specimen contains natural dry lumps, those that are about ½ in. (12 mm) in diameter may be used in place of the molded balls.

NOTE 10—The process of molding and drying usually produces higher strengths than are found in natural dry lumps of soil.

14.2.4 Test the strength of the dry balls or lumps by crushing between the fingers. Note the strength as none, low, medium, high, or very high in accordance with the criteria in Table 8. If natural dry lumps are used, do not use the results of any of the lumps that are found to contain particles of coarse sand.

14.2.5 The presence of high-strength water-soluble cementing materials, such as calcium carbonate, may cause exceptionally high dry strengths. The presence of calcium carbonate can usually be detected from the intensity of the reaction with dilute hydrochloric acid (see 10.6).

14.3 Dilatancy:

14.3.1 From the specimen, select enough material to mold into a ball about ½ in. (12 mm) in diameter. Mold the material, adding water if necessary, until it has a soft, but not sticky, consistency.

14.3.2 Smooth the soil ball in the palm of one hand with the blade of a knife or small spatula. Shake horizontally, striking the side of the hand vigorously against the other hand several times. Note the reaction of water appearing on

TABLE 8 Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface

TABLE 9 Criteria for Describing Dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

TABLE 10 Criteria for Describing Toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

the surface of the soil. Squeeze the sample by closing the hand or pinching the soil between the fingers, and note the reaction as none, slow, or rapid in accordance with the criteria in Table 9. The reaction is the speed with which water appears while shaking, and disappears while squeezing.

14.4 Toughness:

14.4.1 Following the completion of the dilatancy test, the test specimen is shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about $\frac{1}{8}$ in. (3 mm) in diameter. (If the sample is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation.) Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about $\frac{1}{8}$ in. The thread will crumble at a diameter of $\frac{1}{8}$ in. when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

14.4.2 Describe the toughness of the thread and lump as low, medium, or high in accordance with the criteria in Table 10.

14.5 Plasticity—On the basis of observations made during the toughness test, describe the plasticity of the material in accordance with the criteria given in Table 11.

14.6 Decide whether the soil is an *inorganic* or an *organic* fine-grained soil (see 14.8). If inorganic, follow the steps given in 14.7.

14.7 Identification of Inorganic Fine-Grained Soils:

TABLE 11 Criteria for Describing Plasticity

Description	Criteria
Nonplastic	A $\frac{1}{8}$ -in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

14.7.1 Identify the soil as a *lean clay*, CL, if the soil has medium to high dry strength, no or slow dilatancy medium toughness and plasticity (see Table 12).

14.7.2 Identify the soil as a *fat clay*, CH, if the soil has high to very high dry strength, no dilatancy, and toughness and plasticity (see Table 12).

14.7.3 Identify the soil as a *silt*, ML, if the soil has low dry strength, slow to rapid dilatancy, and low toughness and plasticity, or is nonplastic (see Table 12).

14.7.4 Identify the soil as an *elastic silt*, MH, if the soil has low to medium dry strength, no to slow dilatancy, and low to medium toughness and plasticity (see Table 12).

NOTE 11—These properties are similar to those for a lean clay. However, the silt will dry quickly on the hand and have a smooth feel when dry. Some soils that would classify as MH in accordance with the criteria in Test Method D 2487 are visually difficult to distinguish from lean clays, CL. It may be necessary to perform laboratory tests for proper identification.

14.8 Identification of Organic Fine-Grained Soils:

14.8.1 Identify the soil as an *organic soil*, OL/OH, if the soil contains enough organic particles to influence the properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soil changes color, for example, black to brown, when exposed to the air. Some organic soils will lighten in color significantly when air dried. Organic soils normally will not have a toughness or plasticity. The thread for the toughness test is spongy.

NOTE 12—In some cases, through practice and experience, it is possible to further identify the organic soils as organic silts or clays, OL or OH. Correlations between the dilatancy, dry strength tests, and laboratory tests can be made to identify organic soils in certain deposits of similar materials of known geologic origin.

14.9 If the soil is estimated to have 15 to 25 % sand, gravel, or both, the words "with sand" or "with gravel" (whichever is more predominant) shall be added to the group name. For example: "lean clay with sand, CL" or "silt with gravel, ML" (see Figs. 1a and 1b). If the percentage of sand is equal to the percentage of gravel, use "with sand."

14.10 If the soil is estimated to have 30 % or more sand, gravel, or both, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if there appears to be more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand. For example: "sandy lean clay, CL", "gravelly fat clay, CH", "sandy silt, ML" (see Figs. 1a and 1b). If the percentage of sand is equal to the percentage of gravel, use "sandy."

15. Procedure for Identifying Coarse-Grained Soils (Soils Containing Less Than 50 % Fines)

15.1 The soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand.

TABLE 12 Identification of Inorganic Fine-Grained Soils from Manual Tests

Soil Symbol	Dry Strength	Dilatancy	Toughness
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High

15.2 The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage of sand.

15.3 The soil is a *clean gravel* or *clean sand* if the percentage of fines is estimated to be 5 % or less.

15.3.1 Identify the soil as a *well-graded gravel*, GW, or as a *well-graded sand*, SW, if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes.

15.3.2 Identify the soil as a *poorly graded gravel*, GP, or as a *poorly graded sand*, SP, if it consists predominantly of one size (uniformly graded), or it has a wide range of sizes with some intermediate sizes obviously missing (gap or skip graded).

15.4 The soil is either a *gravel with fines* or a *sand with fines* if the percentage of fines is estimated to be 15 % or more.

15.4.1 Identify the soil as a *clayey gravel*, GC, or a *clayey sand*, SC, if the fines are clayey as determined by the procedures in Section 14.

15.4.2 Identify the soil as a *silty gravel*, GM, or a *silty sand*, SM, if the fines are silty as determined by the procedures in Section 14.

15.5 If the soil is estimated to contain 10 % fines, give the soil a dual identification using two group symbols.

15.5.1 The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, SM).

15.5.2 The group name shall correspond to the first group symbol plus the words "with clay" or "with silt" to indicate the plasticity characteristics of the fines. For example: "well-graded gravel with clay, GW-GC" or "poorly graded and with silt, SP-SM" (see Fig. 2).

15.6 If the specimen is predominantly sand or gravel but contains an estimated 15 % or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example: "poorly graded gravel with sand, GP" or "clayey sand with gravel, SC" (see Fig. 2).

15.7 If the field sample contains any cobbles or boulders, or both, the words "with cobbles" or "with cobbles and boulders" shall be added to the group name. For example: "silty gravel with cobbles, GM."

6. Report

16.1 The report shall include the information as to origin, and the items indicated in Table 13.

NOTE 13—Example: *Clayey Gravel with Sand and Cobbles, GC*—about 50 % fine to coarse, subrounded to subangular gravel; about 30 % fine to coarse, subrounded sand; about 20 % fines with medium plasticity, high dry strength, no dilatancy, medium toughness; weak

TABLE 13 Checklist for Description of Soils

1. Group name
2. Group symbol
3. Percent of cobbles or boulders, or both (by volume)
4. Percent of gravel, sand, or fines, or all three (by dry weight)
5. Particle-size range:
Gravel—fine, coarse
Sand—fine, medium, coarse
6. Particle angularity: angular, subangular, subrounded, rounded
7. Particle shape: (if appropriate) flat, elongated, flat and elongated
8. Maximum particle size or dimension
9. Hardness of coarse sand and larger particles
10. Plasticity of fines: nonplastic, low, medium, high
11. Dry strength: none, low, medium, high, very high
12. Dilatancy: none, slow, rapid
13. Toughness: low, medium, high
14. Color (in moist condition)
15. Odor (mention only if organic or unusual)
16. Moisture: dry, moist, wet
17. Reaction with HCl: none, weak, strong
For intact samples:
18. Consistency (fine-grained soils only): very soft, soft, firm, hard, very hard
19. Structure: stratified, laminated, fissured, slickensided, lensed, homogeneous
20. Cementation: weak, moderate, strong
21. Local name
22. Geologic interpretation
23. Additional comments: presence of roots or root holes, presence of mica, gypsum, etc., surface coatings on coarse-grained particles, caving or sloughing of auger hole or trench sides, difficulty in augering or excavating, etc.

reaction with HCl; original field sample had about 5 % (by volume) subrounded cobbles, maximum dimension, 150 mm.

In-Place Conditions—Firm, homogeneous, dry, brown

Geologic Interpretation—Alluvial fan

NOTE 14—Other examples of soil descriptions and identification are given in Appendixes X1 and X2.

NOTE 15—If desired, the percentages of gravel, sand, and fines may be stated in terms indicating a range of percentages, as follows:

Trace—Particles are present but estimated to be less than 5 %

Few—5 to 10 %

Little—15 to 25 %

Some—30 to 45 %

Mostly—50 to 100 %

16.2 If, in the soil description, the soil is identified using a classification group symbol and name as described in Test Method D 2487, it must be distinctly and clearly stated in log forms, summary tables, reports, and the like, that the symbol and name are based on visual-manual procedures.

17. Precision and Bias

17.1 This practice provides qualitative information only, therefore, a precision and bias statement is not applicable.

18. Keywords

18.1 classification; clay; gravel; organic soils; sand; silt; soil classification; soil description; visual classification



Standard Guide for Sampling Groundwater Monitoring Wells¹

This standard is issued under the fixed designation D 4448; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers procedures for obtaining valid, representative samples from groundwater monitoring wells. The scope is limited to sampling and "in the field" preservation and does not include well location, depth, well development, design and construction, screening, or analytical procedures.

1.2 This guide is only intended to provide a review of any of the most commonly used methods for sampling groundwater quality monitoring wells and is not intended to serve as a groundwater monitoring plan for any specific application. Because of the large and ever increasing number of options available, no single guide can be viewed as comprehensive. The practitioner must make every effort to ensure that the methods used, whether or not they are described in this guide, are adequate to satisfy the monitoring objectives at each site.

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Summary of Guide

1 The equipment and procedures used for sampling a monitoring well depend on many factors. These include, but are not limited to, the design and construction of the well, the direction of groundwater flow, and the chemical species of interest. Sampling procedures will be different if analyzing for trace organics, volatiles, oxidizable species, or trace metals is needed. This guide considers all of these factors by discussing equipment and procedure options at each stage of the sampling sequence. For ease of organization, the sampling process can be divided into three steps: well flushing, sample withdrawal, and field preparation of samples.

2 Monitoring wells must be flushed prior to sampling so that the groundwater is sampled, not the stagnant water in the well casing. If the well casing can be emptied, this may be desirable although it may be necessary to avoid oxygen contact with the groundwater. If the well cannot be emptied, procedures must be established to demonstrate that the sample represents groundwater. Monitoring an indicative parameter such as pH during flushing is desirable if such a parameter can be identified.

2.3 The types of species that are to be monitored as well as the concentration levels are prime factors for selecting sampling devices (1, 2).² The sampling device and all materials and devices the water contacts must be constructed of materials that will not introduce contaminants or alter the analyte chemically in any way.

2.4 The method of sample withdrawal can vary with the parameters of interest. The ideal sampling scheme would employ a completely inert material, would not subject the sample to negative pressure and only moderate positive pressure, would not expose the sample to the atmosphere, preferably, any other gaseous atmosphere before conveying it to the sample container or flow cell for on-site analysis.

2.5 The degree and type of effort and care that goes into a sampling program is always dependent on the chemical species of interest and the concentration levels of interest. The concentration level of the chemical species of analytical interest decreases, the work and precautions necessary for sampling are increased. Therefore, the sampling objectives must clearly be defined ahead of time. For example, preparing equipment for sampling for mg/L (ppm) levels of Total Organic Carbon (TOC) in water is about an order of magnitude easier than preparing to sample for $\mu\text{g/L}$ (ppb) levels of a trace organic like benzene. The specific precautions to be taken in preparing to sample for trace organics are different from those to be taken in sampling for trace metals. No final Environmental Protection Agency (EPA) protocol is available for sampling of trace organics. A short guidance manual, (3) and an EPA document (4) concerning monitoring well sampling, including considerations for trace organics are available.

2.6 Care must be taken not to cross contaminate samples or monitoring wells with sampling or pumping devices or materials. All samples, sampling devices, and containers must be protected from the environment when not in use. Water level measurements should be made before the well is flushed. Oxidation-reduction potential, pH, dissolved oxygen, and temperature measurements and filtration should all be performed on the sample in the field, if possible. All but temperature measurement must be done prior to any significant atmospheric exposure, if possible.

2.7 The sampling procedures must be well planned and all sample containers must be prepared and labeled prior to going to the field.

3. Significance and Use

3.1 The quality of groundwater has become an issue of national concern. Groundwater monitoring wells are one of

¹ This guide is under the jurisdiction of ASTM Committee D-34 on Waste Disposal and is the direct responsibility of Subcommittee D34.01 on Sampling and Testing.

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² The boldface numbers in parentheses refer to a list of references at the end of this guide.

TABLE 1 Typical Container and Preservation Requirements for a Ground-Water Monitoring Program

Sample and Measurement	Volume Required (mL)	Container P—Polyethylene G—Glass	Preservative	Maximum Holding Time
Metals As/Ba/Cd/Cr/Fe Pb/Se/ Ag/Mn/Na	1000–2000	P/G (special acid cleaning)	high purity nitric acid to pH <2	6 months
Mercury	200–300	P/G (special acid cleaning)	high purity nitric acid to pH <2 +0.05 % K ₂ Cr ₂ O ₇	28 days
Radioactivity alpha/beta/radium	4000	P/G (special acid cleaning)	high purity nitric acid to pH <2	6 months
Phenolics	500–1000	G	cool, 4°C H ₂ SO ₄ to pH <2	28 days
Miscellaneous	1000–2000	P	cool, 4°C	28 days
Fluoride	300–500	P		28 days
Chloride	50–200	P/G		28 days
Sulfate	100–500	P/G		48 hours
Nitrate	100–250	P/G		6 h
Coliform	100	P/G		on site/24 h
Conductivity	100	P/G		on site/6 h
pH	100	P/G		48 h
Turbidity	100	P/G		
Total organic carbon (TOC)	25–100	P/G	cool, 4°C or cool, 4°C HCl or H ₂ SO ₄ to pH <2	24 h 28 days
Pesticides, herbicides and total organic halogen (TOX)	1000–4000	G/TFE-fluorocarbon lined cap solvent rinsed	cool, 4°C	7 days/extraction + days/analysis
Extractable organics	1000–2000	G/TFE-fluorocarbon-lined cap solvent rinsed	cool, 4°C	7 days/extraction + days/analysis
Organic purgeables acrolein/acrylonitrile	25–120	G/vial TFE-fluorocarbon-lined septum	cool, 4°C	14 days 3 days

the more important tools for evaluating the quality of groundwater, delineating contamination plumes, and establishing the integrity of hazardous material management facilities.

3.2 The goal in sampling groundwater monitoring wells is to obtain samples that are truly representative of the aquifer or groundwater in question. This guide discusses the advantages and disadvantages of various well flushing, sample withdrawal, and sample preservation techniques. It reviews the parameters that need to be considered in developing a valid sampling plan.

4. Well Flushing (Purging)

4.1 Water that stands within a monitoring well for a long period of time may become unrepresentative of formation water because chemical or biochemical change may cause water quality alterations and even if it is unchanged from the time it entered the well, the stored water may not be representative of formation water at the time of sampling, or both. Because the representativeness of stored water is questionable, it should be excluded from samples collected from a monitoring well.

4.2 The surest way of accomplishing this objective is to remove all stored water from the casing prior to sampling. Research with a tracer in a full scale model 2 in. PVC well (5) indicates that pumping 5 to 10 times the volume of the well via an inlet near the free water surface is sufficient to remove all the stored water in the casing. The volume of the well may

be calculated to include the well screen and any gravel pack if natural flow through these is deemed insufficient to keep them flushed out.

4.3 In deep or large diameter wells having a volume of water so large as to make removal of all the water impractical, it may be feasible to lower a pump or pump inlet to some point well below the water surface, purge only the volume below that point then withdraw the sample from the deeper level. Research indicates this approach should avoid most contamination associated with stored water (5, 6). Sealing the casing above the purge point with a packer may make this approach more dependable by preventing migration of stored water from above. But the packer must be above the top of the screened zone, or stagnant water from above the packer will flow into the purged zone through the well's gravel/sand pack.

4.4 In low yielding wells, the only practical way to remove all standing water may be to empty the casing. Since it is not always possible to remove all water, it may be advisable to allow the well to recover (refill) and empty it again at least once. The introduction of oxygen into the aquifer may be of concern. It would be best not to uncover the screen when performing the above procedures. The main disadvantage of methods designed to remove all the stored water is that large volumes may need to be pumped in certain instances. The main advantage is that the potential for contamination of the well with stored water is minimized.

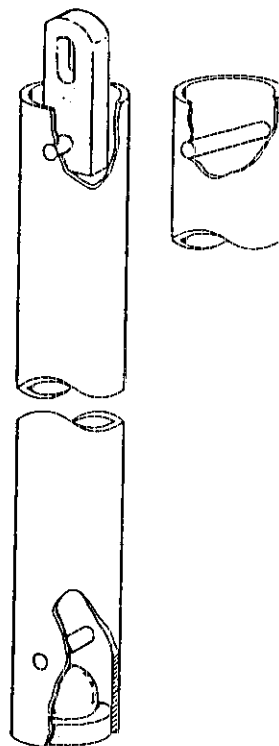


FIG. 1 Single Check Valve Bailer

Note---Taken from Ref (15).

4.5 Another approach to well flushing is to monitor one or more indicator parameters such as pH, temperature, or conductivity and consider the well to be flushed when the indicator(s) no longer change. The advantage of this method is that pumping can be done from any location within the casing and the volume of stored water present has no direct bearing on the volume of water that must be pumped. Obviously, in a low yielding well, the well may be emptied before the parameters stabilize. A disadvantage of this approach is that there is no assurance in all situations that the stabilized parameters represent formation water. If significant drawdown has occurred, water from some distance away may be pulled into the screen causing a steady parameter reading but not a representative reading. Also, a suitable indicator parameter and means of continuously measuring it in the field must be available.

4.6 Gibb (4, 8) has described a time-drawdown approach using a knowledge of the well hydraulics to predict the percentage of stored water entering a pump inlet near the top of the screen at any time after flushing begins. Samples are taken when the percentage is acceptably low. As before, the advantage is that well volume has no direct effect in the duration of pumping. A current knowledge of the well's hydraulic characteristics is necessary to employ this approach. Downward migration of stored water due to effects other than drawdown (for example density differences) is not accounted for in this approach.

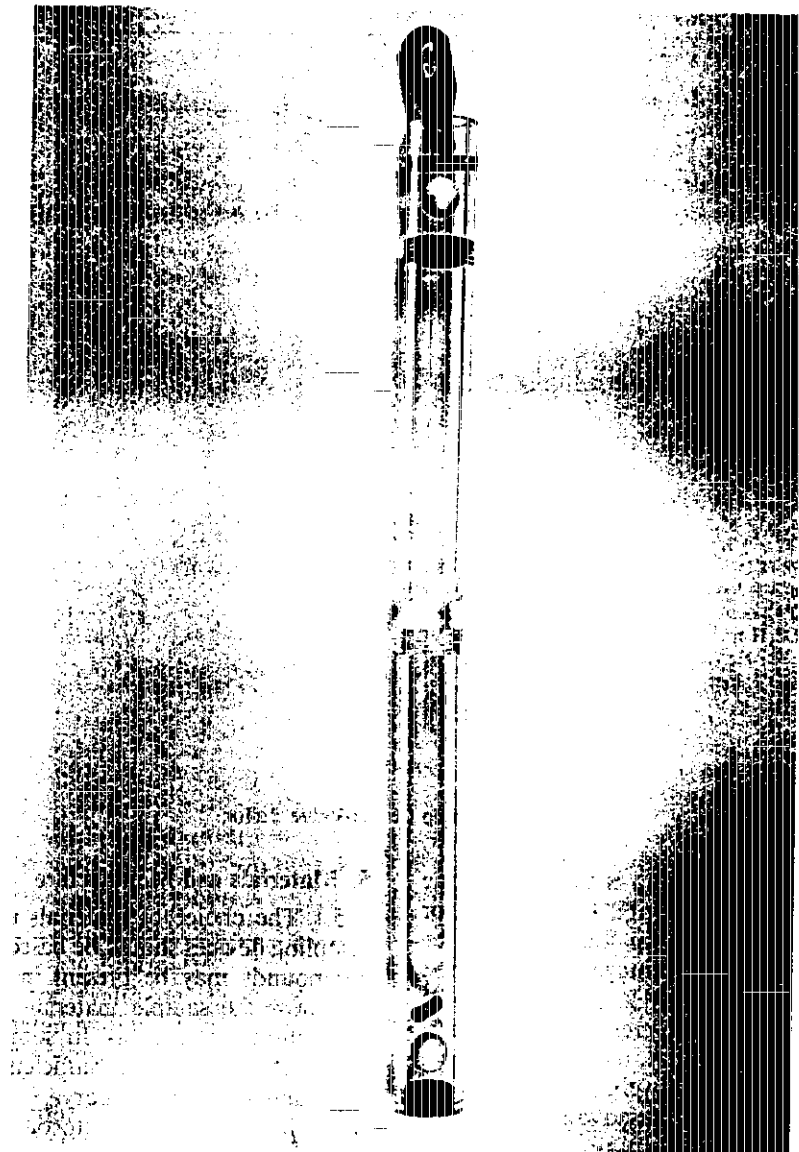
4.7 In any flushing approach, a withdrawal rate that minimizes drawdown while satisfying time constraints should be used. Excessive drawdown distorts the natural flow patterns around a well and can cause contaminants that were not present originally to be drawn into the well.

5. Materials and Manufacture

5.1 The choice of materials used in the construction of sampling devices should be based upon a knowledge of what compounds may be present in the sampling environment and how the sample materials may interact via leaching, adsorption, or catalysis. In some situations, PVC or some other plastic may be sufficient. In others, an all glass apparatus may be necessary.

5.2 Most analytical protocols suggest that the devices used in sampling and storing samples for trace organics analysis ($\mu\text{g/L}$ levels) must be constructed of glass or TFE-fluorocarbon resin, or both. One suggestion advanced by the EPA is that the monitoring well be constructed so that only TFE-fluorocarbon tubing be used in that portion of the sampling well that extends from a few feet above the water table to the bottom of the borehole. (3, 5) Although this type of well casing is now commercially available, PVC well casings are currently the most popular. If adhesives are avoided, PVC well casings are acceptable in many cases although their use may still lead to some problems if trace organics are of concern. At present, the type of background presented by PVC and interactions occurring between PVC and groundwater are not well understood. Tin, in the form of an organotin stabilizer added to PVC, may enter samples taken from PVC casing. (9)

5.3 Since the most significant problem encountered in trace organics sampling, results from the use of PVC adhesives in monitoring well construction, threaded joints might avoid the problem (3, 5). Milligram per litre (parts per million) levels of compounds such as tetrahydrofuran, methyl-ethyl-ketone, and toluene are found to leach into



NOTE—Taken from Ref (17).

FIG. 2 Acrylic Point Source Bailer

groundwater samples from monitoring well casings sealed with PVC solvent cement. Pollutant phthalate esters (8, 10) are often found in water samples at ppb levels; the EPA has found them on occasion at ppm levels in their samples. The ubiquitous presence of these phthalate esters is unexplained, except to say that they may be leached from plastic pipes, sampling devices, and containers.

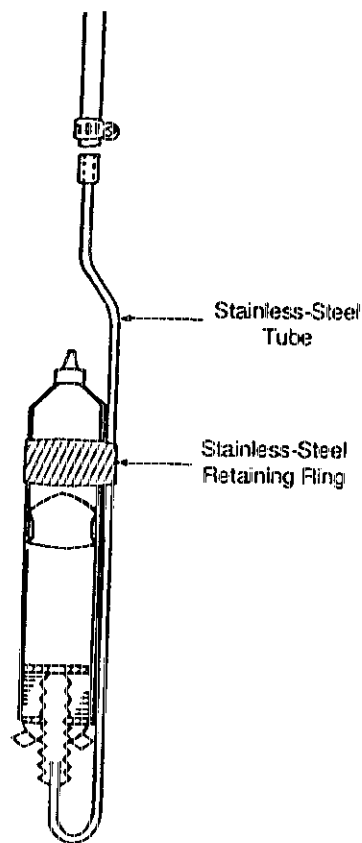
5.4 TFE-fluorocarbon resins are highly inert and have sufficient mechanical strength to permit fabrication of sampling devices and well casings. Molded parts are exposed to high temperature during fabrication which destroys any organic contaminants. The evolution of fluorinated compounds can occur during fabrication, will cease rapidly, and does not occur afterwards unless the resin is heated to its melting point.

5.5 Extruded tubing of TFE-fluorocarbon for sampling may contain surface traces of an organic solvent extrusion aid. This can be removed easily by the fabricator and, once

removed by flushing, should not affect the sample. TF fluorocarbon FEP and TFE-fluorocarbon PFA resins do not require this extrusion aid and may be suitable for sampling tubing as well. Unsintered thread-sealant tape of TF fluorocarbon is available in an "oxygen service" grade and contains no extrusion aid and lubricant.

5.6 Louneman, et al. (11) alludes to problems caused by lubricating oil used during TFE-fluorocarbon tubing extrusion. This reference also presents evidence that a fluorinated ethylene-propylene copolymer adsorbed acetone to a degree that later caused contamination of a gas sample.

5.7 Glass and stainless steel are two other materials generally considered inert in aqueous environments. Glass is probably among the best choices though it is not inconceivable it could adsorb some constituents as well as release other contaminants (for example, Na, silicate, and Fe). Of course glass sampling equipment must be handled carefully in the field. Stainless steel is strong and easily machined and



Note.—Taken from Ref (21).

FIG. 3 Schematic of the Inverted Syringe Sampler

fabricate equipment. Unfortunately, it is not totally immune to corrosion that could release metallic contaminants. Stainless steel contains various alloying metals, some of these (for example Ni) are commonly used as catalysts for various reactions. The alloyed constituents of some stainless steels can be solubilized by the pitting action of nonoxidizing anions such as chloride, fluoride, and in some instances sulfate, over a range of pH conditions. Aluminum, titanium, polyethylene, and other corrosion resistant materials have been proposed by some as acceptable materials, depending on groundwater quality and the constituents of interest.

5.8 Where temporarily installed sampling equipment is used, the sampling device that is chosen should be non-plastic (unless TFE-fluorocarbon), cleanable of trace organics, and must be cleaned between each monitoring well use in order to avoid cross-contamination of wells and samples. The only way to ensure that the device is indeed "clean" and acceptable is to analyze laboratory water blanks and field water blanks that have been soaked in and passed through the sampling device to check for the background levels that may result from the sampling materials or from field conditions. Thus, all samplings for trace materials should be accompanied by samples which represent the field background (if possible), the sampling equipment background, and the laboratory background.

5.9 Additional samples are often taken in the field and spiked (spiked-field samples) in order to verify that the sample handling procedures are valid. The American Chem-

ical Society's committee on environmental improvement has published guidelines for data acquisition and data evaluation which should be useful in such environmental evaluation (10, 12).

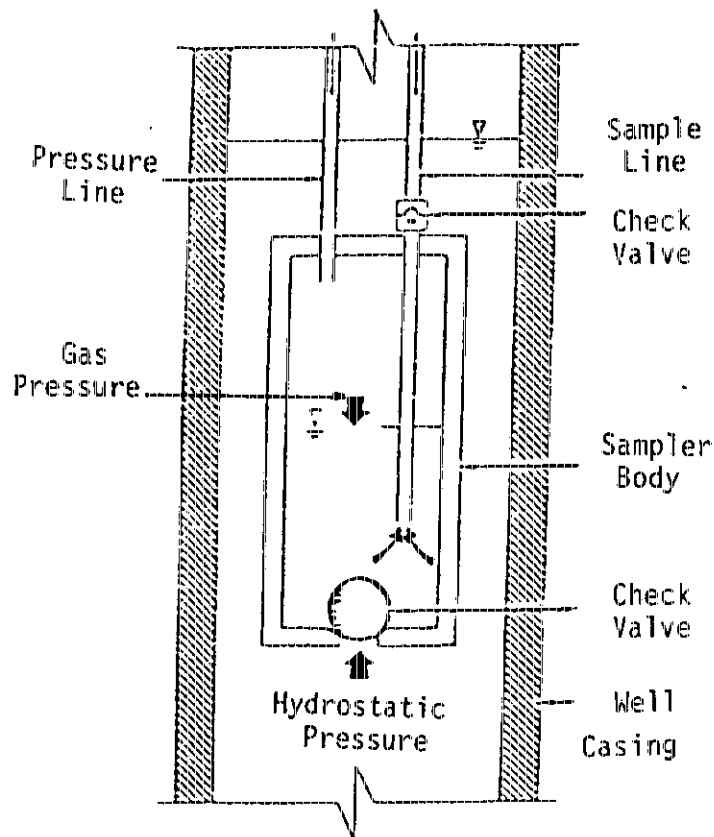
6. Sampling Equipment

6.1 There is a fairly large choice of equipment present available for groundwater sampling from single screened wells and well clusters. The sampling devices can be categorized into the following eight basic types.

6.1.1 Down-Hole Collection Devices:

6.1.1.1 Bailers, messenger bailers, or thief samplers (1, 14) are examples of down-hole devices that probably provide valid samples once the well has been flushed. They are not practical for removal of large volumes of water. These devices can be constructed in various shapes and sizes from a variety of materials. They do not subject the sample to pressure extremes.

6.1.1.2 Bailers do expose part of the sample to the atmosphere during withdrawal. Bailers used for sampling of volatile organic compounds should have a sample cock or draft valve in or near the bottom of the sampler allowing withdrawal of a sample from the well below the exposed surface of the water or the first few inches of the sample should be discarded. Suspension lines for bailers and other samplers should be kept off the ground and free of other contaminating materials that could be carried into the well. Down-hole devices are not very practical for use in deep



NOTE—Taken from Ref (5).

FIG. 4 The Principal of Gas Displacement Pumping

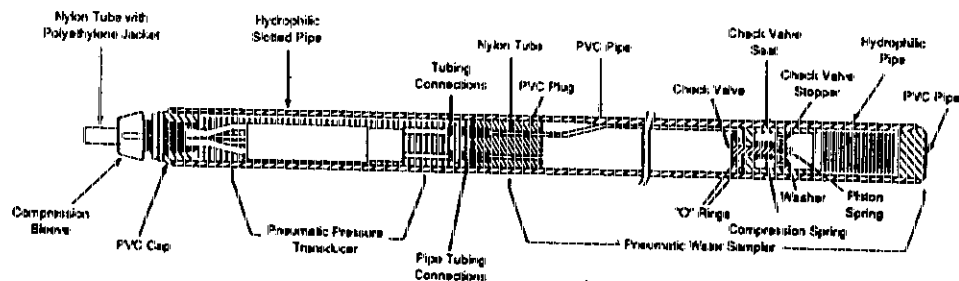
wells. However, potential sample oxidation during transfer of the sample into a collection vessel and time constraints for lowering and retrieval for deep sampling are the primary disadvantages.

6.1.1.3 Three down-hole devices are the single and double check valve bailers and thief samplers. A schematic of a single check valve unit is illustrated in Fig. 1. The bailer may be threaded in the middle so that additional lengths of blank casing may be added to increase the sampling volume. TFE-fluorocarbon or PVC are the most common materials used for construction (15).

6.1.1.4 In operation, the single check valve bailer is lowered into the well, water enters the chamber through the bottom, and the weight of the water column closes the check

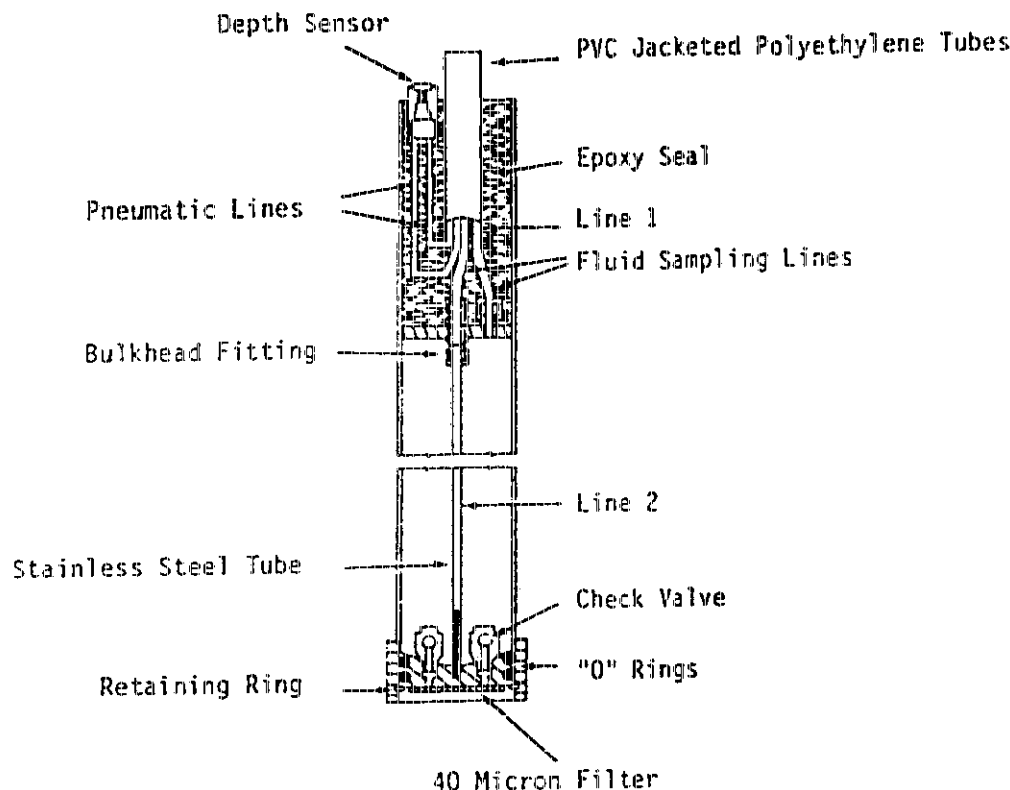
valve upon bailer retrieval. The specific gravity of the sample should be about 1.4 to 2.0 so that the ball almost sits on check valve seat during chamber filling. Upon bailer withdrawal, the ball will immediately seat without any sample loss through the check valve. A similar technique involves lowering a sealed sample container within a weighted bailer into the well. The stopper is then pulled from the bottle via line and the entire assembly is retrieved upon filling of container (14, 16).

6.1.1.5 A double check valve bailer allows point source sampling at a specific depth (15, 17). An example is shown in Fig. 2. In this double check valve design, water flows through the sample chamber as the unit is lowered. A venturi taper inlet and outlet ensures that water passes freely through the



NOTE—Taken from Ref (41).

FIG. 5 Pneumatic Water Sampler With Internal Transducer



NOTE—Taken from Ref (42).

FIG. 6 Pneumatic Sampler With Externally Mounted Transducer

nit. When a depth where the sample is to be collected is reached, the unit is retrieved. Because the difference between each ball and check valve seat is maintained by a pin that blocks vertical movement of the check ball, both check valves close simultaneously upon retrieval. A drainage pin is placed into the bottom of the bailer to drain the sample directly into a collection vessel to reduce the possibility of air oxidation. The acrylic model in Fig. 2 is threaded at the midsection allowing the addition of threaded casing to increase the sampling volume.

6.1.1.6 Another approach for obtaining point source samples employs a weighted messenger or pneumatic change to "trip" plugs at either end of an open tube (for example, tube water sampler or thief sampler) to close the chamber (18). Foerst, Kemmerer, and Bacon samplers are of this variety (14, 17, 19). A simple and inexpensive pneumatic sampler was recently described by Gillham (20). The device (Fig. 3) consists of a disposable 50 mL plastic syringe modified by sawing off the plunger and the finger grips. The syringe is then attached to a gas-line by means of a rubber stopper assembly. The gas-line extends to the surface, and is used to drive the stem-less plunger, and to raise and lower the syringe into the hole. When the gas-line is pressurized, the rubber plunger is held at the tip of the syringe. The sampler is then lowered into the installation, and when the desired depth is reached, the pressure in the gas-line is reduced to atmospheric (or slightly less) and water enters the syringe. The sampler is then retrieved from the installation and the syringe detached from the gas-line. After the tip is sealed, the syringe is used as a short-term storage container. A number

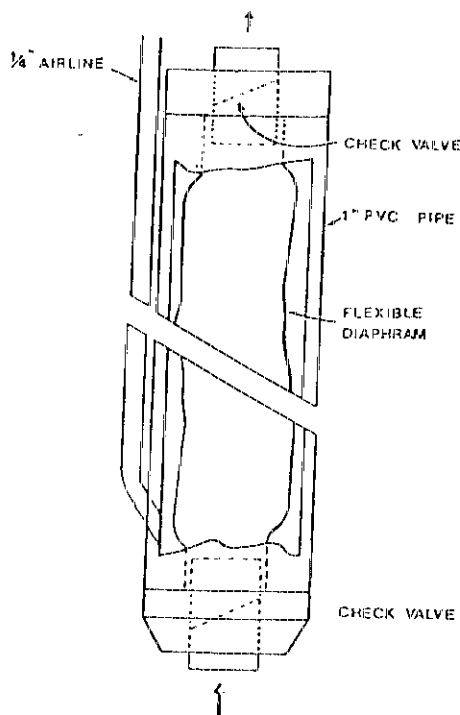
of thief or messenger devices are available in various materials and shapes.

6.1.2 Suction Lift Pumps:

6.1.2.1 Three types of suction lift pumps are the direct line, centrifugal, and peristaltic. A major disadvantage of any suction pump is that it is limited in its ability to raise water by the head available from atmospheric pressure. Thus, if the surface of the water is more than about 25 ft below the pump, water may not be withdrawn. The theoretical suction limit is about 34 ft, but most suction pumps are capable of maintaining a water lift of only 25 ft or less.

6.1.2.2 Many suction pumps draw the water through some sort of volute in which impellers, pistons, or other devices operate to induce a vacuum. Such pumps are probably unacceptable for most sampling purposes because they are usually constructed of common materials such as brass or mild steel and may expose samples to lubricants. They often induce very low pressures around rotating vanes or other such parts such that degassing or even cavitation may occur. They can mix air with the sample via small leaks in the casing, and they are difficult to adequately clean between uses. Such pumps are acceptable for purging of wells, but should not generally be used for sampling.

6.1.2.3 One exception to the above statements is a peristaltic pump. A peristaltic pump is a self-priming, low volume suction pump which consists of a rotor with ball bearing rollers (21). Flexible tubing is inserted around the pump rotor and squeezed by heads as they revolve in a circular pattern around the rotor. One end of the tubing is placed into the well while the other end can be connected



NOTE—Taken from Ref (4).

FIG. 7 Bladder Pump

directly to a receiving vessel. As the rotor moves, a reduced pressure is created in the well tubing and an increased pressure (<40 psi) on the tube leaving the rotor head. A drive shaft connected to the rotor head can be extended so that multiple rotor heads can be attached to a single drive shaft.

6.1.2.4 The peristaltic pump moves the liquid totally within the sample tube. No part of the pump contacts the liquid. The sample may still be degassed (cavitation is unlikely) but the problems due to contact with the pump mechanism are eliminated. Peristaltic pumps do require a fairly flexible section of tubing within the pumphead itself. A section of silicone tubing is commonly used within the peristaltic pumphead, but other types of tubing can be used particularly for the sections extending into the well or from the pump to the receiving container. The National Council of the Paper Industry for Air and Stream Improvement (22) recommends using medical grade silicone tubing for organic sampling purposes as the standard grade uses an organic vulcanizing agent which has been shown to leach into samples. Medical grade silicone tube is, however, limited to use over a restricted range of ambient temperatures. Various manufacturers offer tubing lined with TFE-fluorocarbon or Viton³ for use with their pumps. Gibb (1, 8) found little difference between samples withdrawn by a peristaltic pump and those taken by a bailer.

6.1.2.5 A direct method of collecting a sample by suction consists of lowering one end of a length of plastic tubing into the well or piezometer. The opposite end of the tubing is connected to a two way stopper bottle and a hand held or

mechanical vacuum pump is attached to a second tubing leaving the bottle. A check valve is attached between the two lines to maintain a constant vacuum control. A sample then be drawn directly into the collection vessel without contacting the pump mechanism (5, 23, 24).

6.1.2.6 A centrifugal pump can be attached to a length of plastic tubing that is lowered into the well. A foot valve is usually attached to the end of the well tubing to assist in priming the tube. The maximum lift is about 4.6 m (15 ft) for such an arrangement (23, 25, 26).

6.1.2.7 Suction pump approaches offer a simple sample retrieval method for shallow monitoring. The direct line method is extremely portable though considerable oxidation and mixing may occur during collection. A centrifugal pump will agitate the sample to an even greater degree although pumping rates of 19 to 151 Lpm (5 to 40 gpm) can be attained. A peristaltic pump provides a lower sampling rate with less agitation than the other two pumps. The withdrawal rate of peristaltic pumps can be carefully regulated by adjustment of the rotor head revolution.

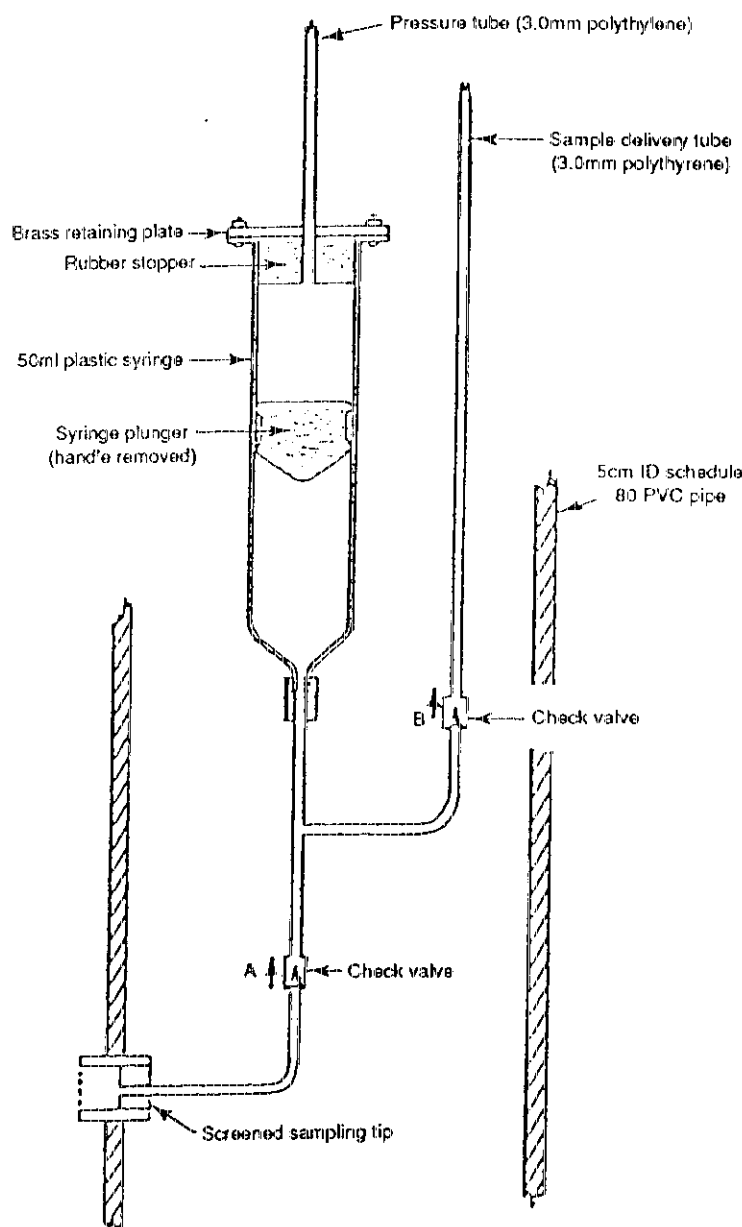
6.1.2.8 All three systems can be specially designed so that the water sample contacts only the TFE fluorocarbon or silicone tubing prior to sample bottle entry. Separate tubing is recommended for each well or piezometer sampled.

6.1.3 Electric Submersible Pumps:

6.1.3.1 A submersible pump consists of a sealed electric motor that powers a piston or helical single thread worm at a high rpm. Water is brought to the surface through an access tube. Such pumps have been used in the water well industry for years and many designs exist (5, 26).

6.1.3.2 Submersible pumps provide relatively high charge rates for water withdrawal at depths beyond suction

³ Viton is a trademark of E. I. du Pont de Nemours & Co., Wilmington, DE 19898 and has been found suitable for this purpose.



Note—Taken from Ref (48).

FIG. 8 Positive Displacement Syringe Pump

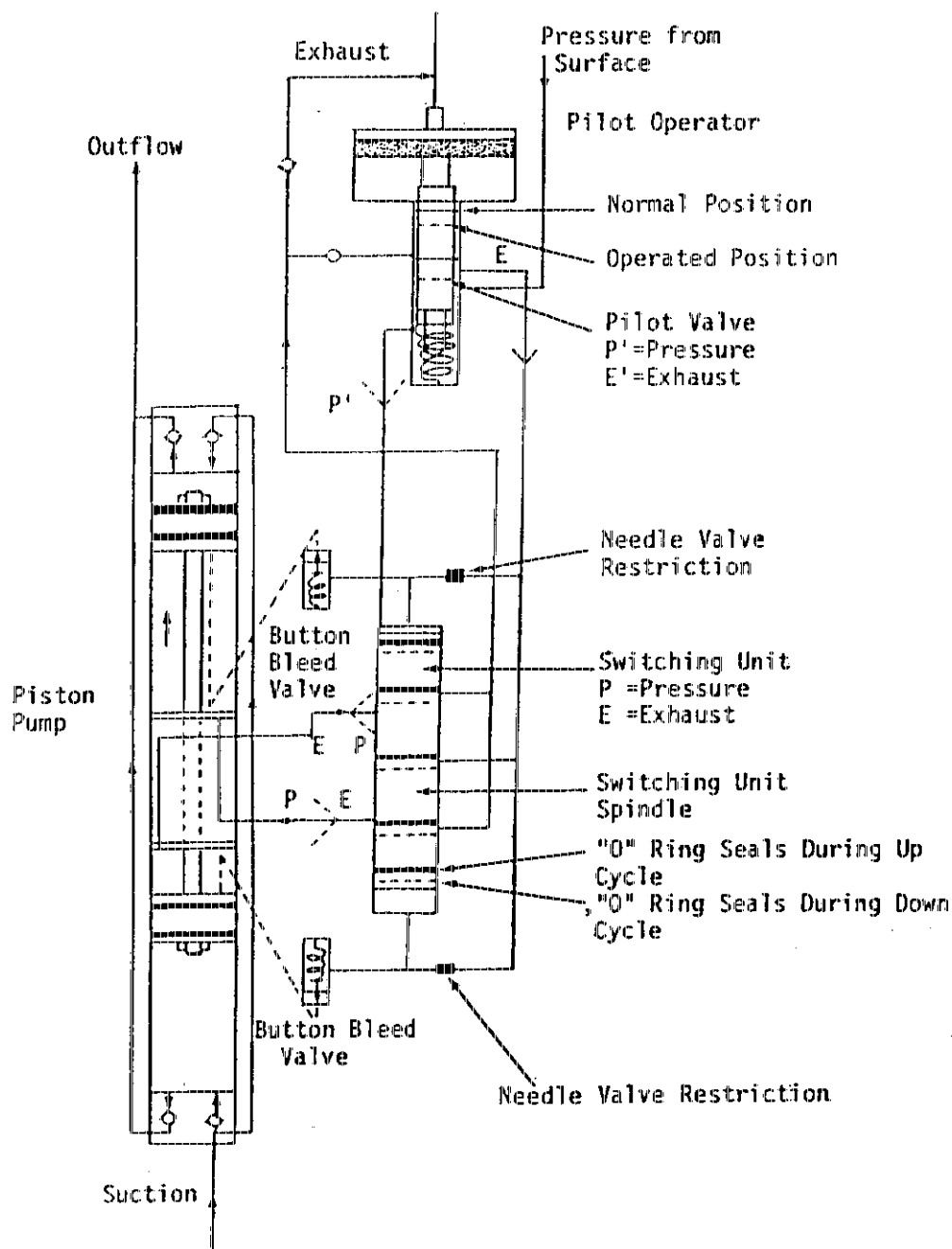
lift capabilities. A battery operated unit 3.6 cm (1.4 in.) in diameter and with a 4.5 Lpm (1.2 gpm) flow rate at 33.5 m (110 ft) has been developed (27). Another submersible pump has an outer diameter of 11.4 cm (4.5 in.) and can pump water from 91 m (300 ft). Pumping rates vary up to 53.0 Lpm (14 gpm) depending upon the depth of the pump (28).

6.1.3.3 A submersible pump provides higher extraction rates than many other methods. Considerable sample agitation results, however, in the well and in the collection tube during transport. The possibility of introducing trace metals into the sample from pump materials also exists. Steam cleaning of the unit followed by rinsing with unchlorinated, deionized water is suggested between sampling when analysis for organics in the parts per million (ppm) or parts per billion (ppb) range is required (29).

6.1.4 Gas-Lift Pumps:

6.1.4.1 Gas-lift pumps use compressed air to bring a water sample to the surface. Water is forced up an eductor pip that may be the outer casing or a smaller diameter pip inserted into the well annulus below the water level (30, 31).

6.1.4.2 A similar principle is used for a unit that consists of a small diameter plastic tube perforated in the lower end. This tube is placed within another tube of slightly larger diameter. Compressed air is injected into the inner tube; the air bubbles through the perforations, thereby lifting the water sample via the annulus between the outer and inner tubing (32). In practice, the eductor line should be submerged to a depth equal to 60 % of the total submerged eductor length during pumping (26). A 60 % ratio is considered optimum although a 30 % submergence ratio is adequate.



NOTE—Taken from Ref (49).

FIG. 9 Gas Driven Piston Pump

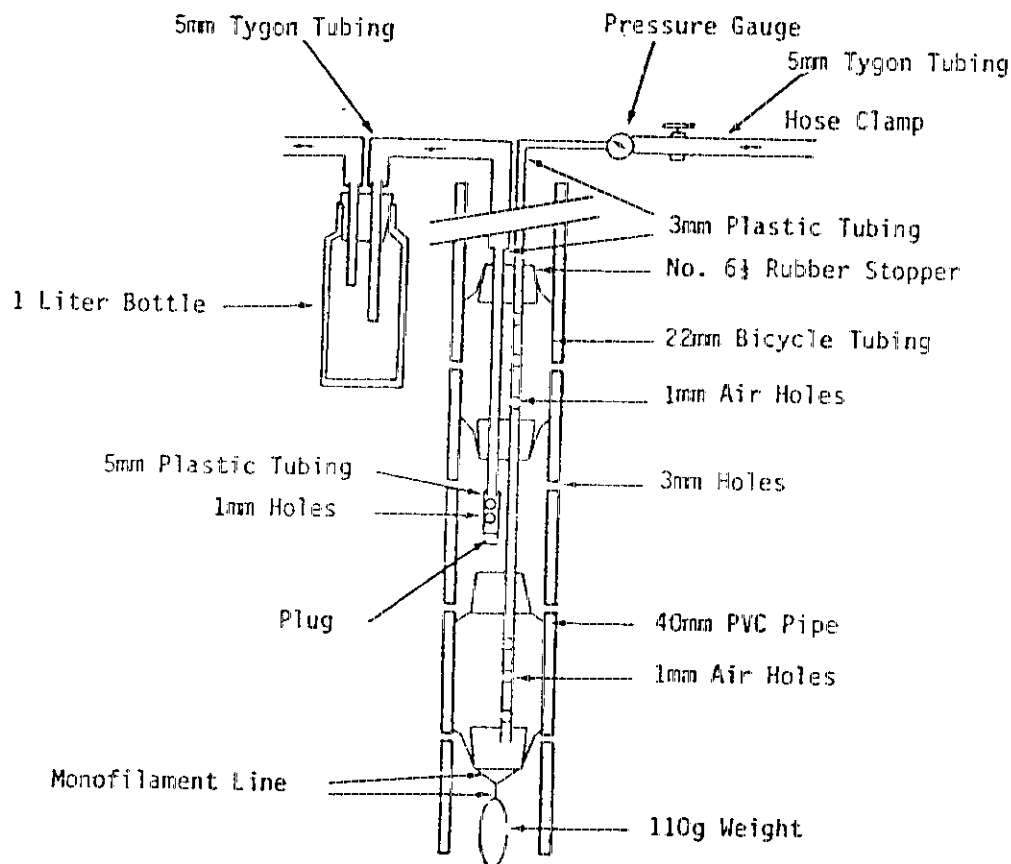
6.1.4.3 The source of compressed gas may be a hand pump for depths generally less than 7.6 m (25 ft). For greater depths, air compressors, pressurized air bottles, and air compressed from an automobile engine have been used.

6.1.4.4 As already mentioned, gas-lift methods result in considerable sample agitation and mixing within the well, and cannot be used for samples which will be tested for volatile organics. The eductor pipe or weighted plastic tubing is a potential source of sample contamination. In addition, Gibb (8) uncovered difficulties in sampling for inorganics. These difficulties were attributed to changes in redox, pH,

and species transformation due to solubility constant changes resulting from stripping, oxidation, and pressure changes.

6.1.5 Gas Displacement Pumps:

6.1.5.1 Gas displacement or gas drive pumps are distinguished from gas-lift pumps by the method of sample transport. Gas displacement pumps force a discrete column of water to the surface via mechanical lift without extensive mixing of the pressurized gas and water as occurs with lift equipment. The principle is shown schematically in Fig. 4. Water fills the chamber. A positive pressure is applied to the



NOTE—Taken from Ref (53).

FIG. 10 Packer Pump Arrangement

gas line closing the sampler check valve and forcing water up the sample line. By removing the pressure the cycle can be repeated. Vacuum can also be used in conjunction with the gas (30). The device can be permanently installed in the well (33, 34, 35) or lowered into the well (36, 37).

6.1.5.2 A more complicated two stage design constructed of glass with check valves made of TFE-fluorocarbon has been constructed (38, 39). The unit was designed specifically for sample testing for trace level organics. Continuous flow rates up to 2.3 Lpm (0.6 gpm) are possible with a 5.1 cm (2 in.) diameter unit.

6.1.5.3 Gas displacement pumps have also been developed with multiple functions. The water sample in Fig. 5 provides piezometric data measurements with an internally mounted transducer (40). A sample with its transducer exposed externally for piezometric measurements is illustrated in Fig. 6 (41). The sensor can activate the gas source at the surface to cause sample chamber pressurization at the predetermined depth. Another design can be used as a water sampler or as a tool for injecting brine or other tracers into a well (42).

6.1.5.4 Gas displacement pumps offer reasonable potential for preserving sample integrity because little of the driving gas comes in contact with the sample as the sample is conveyed to the surface by a positive pressure. There is, however, a potential loss of dissolved gasses or contamination from the driving gas and the housing materials.

6.1.6 Bladder Pumps:

6.1.6.1 Bladder pumps, also referred to as gas-operated squeeze pumps, consist of a flexible membrane enclosed by a rigid housing. Water enters the membrane through a check valve in the vessel bottom; compressed gas injected into the cavity between the housing and bladder forces the sample through a check valve at the top of the membrane and into a discharge line (Fig. 7). Water is prevented from re-entering the bladder by the top check valve. The process is repeated to cycle the water to the surface. Samples taken from depths of 30.5 m (100 ft) have been reported.

6.1.6.2 A variety of design modifications and materials are available (43, 44). Bladder materials include neoprene, rubber, ethylene propylene terpolymer (E.P.T.), nitrile, and the fluorocarbon Viton.³ A bladder made of TFE-fluorocarbon is also under development (45). Automated sampling systems have been developed to control the time between pressurization cycles (46).

6.1.6.3 Bladder pumps provide an adaptable sampling tool due primarily to the number of bladder shapes that are feasible. These devices have a distinct advantage over gas displacement pumps in that there is no contact with the driving gas. Disadvantages include the large gas volumes required, low pumping rates, and potential contamination from many of the bladder materials, the rigid housing, or both.

6.1.7 Gas Driven Piston Pumps:

6.1.7.1 A simple and inexpensive example of a gas driven piston pump is a syringe pump (47). The pump (Fig. 8) is constructed from a 50 mL plastic syringe with plunger stem removed. The device is connected to a gas line to the surface and the sample passes through a check valve arrangement to a sampling container at the surface. By successively applying positive and negative pressure to the gas-line, the plunger is activated driving water to the surface.

6.1.7.2 A double piston pump powered by compressed air is illustrated in Fig. 9. Pressurized gas enters the chamber between the pistons; the alternating chamber pressurization activates the piston which allows water entry during the suction stroke of the piston and forces the sample to the surface during the pressure stroke (48). Pumping rates between 9.5 and 30.3 L/hr (2.5 to 8 gal/hr) have been reported from 30.5 m (100 ft). Depths in excess of 457 m (1500 ft) are possible.

6.1.7.3 The gas piston pump provides continuous sample withdrawal at depths greater than is possible with most other approaches. Nevertheless, contribution of trace elements from the stainless steel and brass is a potential problem and the quantity of gas used is significant.

6.1.8 Packer Pump Arrangement:

6.1.8.1 A packer pump arrangement provides a means by which two expandable "packers" isolate a sampling unit between two packers within a well. Since the hydraulic or pneumatic activated packers are wedged against the casing wall or screen, the sampling unit will obtain water samples only from the isolated well portion. The packers are deflated for vertical movement within the well and inflated when the desired depth is attained. Submersible, gas lift, and suction pumps can be used for sampling. The packers are usually constructed from some type of rubber or rubber compound (48, 49, 50, 51). A packer pump unit consisting of a vacuum sampler positioned between two packers is illustrated in Fig. 10 (52).

6.1.8.2 A packer assembly allows the isolation of discrete sampling points within a well. A number of different samplers can be situated between the packers depending upon the analytical specifications for sample testing. Vertical movement of water outside the well casing during sampling is possible with packer pumps but depends upon the pumping rate and subsequent disturbance. Deterioration of the expandable materials will occur with time with the increased possibility of undesirable organic contaminants contributing to the water sample.

7. Sample Containers and Preservation

7.1 Complete and unequivocal preservation of samples, whether domestic wastewater, industrial wastes, or natural waters, is practically impossible. At best, preservation techniques only retard the chemical and biological changes that inevitably continue after the sample is removed from the source. Therefore, insuring the timely analysis of a sample should be one of the foremost considerations in the sampling plan schedule. Methods of preservation are somewhat limited and are intended to retard biological action, retard hydrolysis of chemical compounds and complexes, and reduce the volatility of constituents. Preservation methods are generally limited to pH control, chemical addition, refrigeration and freezing. For water samples, immediate

refrigeration just above freezing (4°C in wet ice) is often the best preservation technique available, but it is not the only measure nor is it applicable in all cases. There may be special cases where it might be prudent to include a recording thermometer in the sample shipment to verify the maximum and minimum temperature to which the samples were exposed. Inexpensive devices for this purpose are available.

7.2 All bottles and containers must be specially pre-cleaned, pre-labelled, and organized in ice-chests (isolating samples and sampling equipment from the environment) before one goes into the field. Otherwise, in any comprehensive program utter chaos usually develops in the field or laboratory. The time in the field is very valuable and should be spent on taking field notes, measurements, and in documenting samples, not on labelling and organizing samples. Therefore, the sampling plan should include clear instructions to the sampling personnel concerning the information required in the field data record logbook (notebook), the information needed on container labels for identification, the chain-of-custody protocols, and the methods for preparing field blanks and spiked samples. Example of detailed plans and documentation procedures have been published (14, 53).

7.3 The exact requirements for the volumes of sample needed and the number of containers to use may vary from laboratory to laboratory. This will depend on the specific analyses to be performed, the concentration levels of interest, and the individual laboratory protocols. The manager of the sampling program should make no assumptions about the laboratory analyses. He should discuss the analytical requirements of the sampling program in detail with the laboratory coordinator beforehand. This is especially the case for some analyses and preservation measures must be performed at the laboratory as soon as possible after the samples arrive. Thus, appropriate arrangements must be made.

7.4 There are a number of excellent references available which list the containers and preservation techniques appropriate for water and soils (13, 14, 50, 54, 55, 56). The "Handbook for Sampling and Sample Preservation of Water and Wastewater" is an excellent reference and perhaps the most comprehensive one (14). Some of this information is summarized in Table 1.

7.5 Sample containers for trace organic samples require special cleaning and handling considerations (57). The sample container for purgeable organics consist of a screw-cap vial (25 to 125 mL) fitted with a TFE-fluorocarbon faced silicone septum. The vial is sealed in the laboratory immediately after cleaning and is only opened in the field just prior to pouring sample into it. The water sample then must be sealed into the vial headspace free (no air bubbles) and immediately cooled (4°C) for shipment. Multiple samples (usually about four taken from one large sample container) are taken because leakage of containers may cause losses, may allow air to enter the containers, and may cause erroneous analysis of some constituents. Also, some analyses are best conducted on independent protected samples.

7.6 The purgeable samples must be analyzed by the laboratory within 14 days after collection, unless they are to be analyzed for acrolein or acrylonitrile (in which case they are to be analyzed within 3 days). For samples for solid extractions (extractable organics-base neutrals, acids and

pesticides), the sample bottles are narrow mouth, screw cap quart bottles or half-gallon bottles that have been precleaned, rinsed with the extracting organic solvent and oven dried at 105°C for at least 1 h. These bottles must be sealed with TFE-fluorocarbon lined caps (Note). Samples for organic extraction must be extracted within 7 days and analyzed within 30 days after extraction. Special pre-cleaned, solvent rinsed and oven-dried stainless steel beakers (one for each monitoring well) may be used for transferring samples from the sampling device to the sample containers.

NOTE—When collecting samples, the bottles should not be overfilled or prerinsed with sample before filling because oil and other materials may remain in the bottle. This can cause erroneously high results.

7.7 For a number of groundwater parameters, the most meaningful measurements are those made in the field at the time of sample collection or at least at an on-site laboratory. These include the water level in the well and parameters that sometimes can change rapidly with storage. A discussion of the various techniques for measuring the water level in the well is contained in a NCASI publication (5) and detailed procedures are outlined in a U.S. Geological Survey publication (58). Although a discussion of these techniques is beyond the scope of this guide, it is important to point out that accurate measurements must be made before a well is flushed or only after it has had sufficient time to recover. Parameters that can change rapidly with storage include specific conductance, pH, turbidity, redox potential, dissolved oxygen, and temperature. For some of the other

parameters, the emphasis in groundwater monitoring is on the concentration of each specific dissolved component, not the total concentration of each. Samples for these types of measurements should be filtered through 0.45 µm membrane filters ideally in the field or possibly at an on-site laboratory as soon as possible. Analyses often requiring filtered samples include all metals, radioactivity parameters, total organic carbon, dissolved orthophosphate (if needed), and total dissolved phosphorous (if needed) (13, 14). If metals are to be analyzed, filter the sample prior to acid preservation. For TOC organics, the filter material should be tested to assure that it does not contribute to the TOC. The type or size of the filter to be used is not well understood. However, if results of metal, TOC or other parameters that could be effected by solids are to be compared, the same filtering procedure must be used in each case. Repeated analytical results should state whether the samples were filtered and how they were filtered.

7.8 Shipment and receipt of samples must be coordinated with the laboratory to minimize time in transit. All samples for organic analysis (and many other parameters), should arrive at the laboratory within one day after it is shipped and be maintained at about 4°C with wet ice. The best way to get them to the laboratory in good condition is to send them in sturdy insulated ice chests (coolers) equipped with bottle dividers. 24-h courier service is recommended, if personal delivery service is not practical.

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Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)¹

This standard is issued under the fixed designation D 2488; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This practice covers procedures for the description of soils for engineering purposes.

1.2 This practice also describes a procedure for identifying soils, at the option of the user, based on the classification system described in Test Method D 2487. The identification is based on visual examination and manual tests. It must be clearly stated in reporting an identification that it is based on visual-manual procedures.

1.2.1 When precise classification of soils for engineering purposes is required, the procedures prescribed in Test Method D 2487 shall be used.

1.2.2 In this practice, the identification portion assigning a group symbol and name is limited to soil particles smaller than 3 in. (75 mm).

1.2.3 The identification portion of this practice is limited to naturally occurring soils (disturbed and undisturbed).

NOTE 1—This practice may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. (See Appendix X2).

1.3 The descriptive information in this practice may be used with other soil classification systems or for materials other than naturally occurring soils.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific precautionary statements see Section 8.*

1.5 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 ASTM Standards:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids²

D 1452 Practice for Soil Investigation and Sampling by Auger Borings²

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils²

D 1587 Practice for Thin-Walled Tube Sampling of Soils²

D 2113 Practice for Diamond Core Drilling for Site Investigation²

D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)²

D 4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)²

3. Terminology

3.1 Definitions:

3.1.1 Except as listed below, all definitions are in accordance with Terminology D 653.

NOTE 2—For particles retained on a 3-in. (75-mm) US standard sieve, the following definitions are suggested:

Cobbles—particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) sieve, and

Boulders—particles of rock that will not pass a 12-in. (300-mm) square opening.

3.1.1.2 *clay*—soil passing a No. 200 (75- μ m) sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air-dry. For classification, a clay is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index equal to or greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line (see Fig. 3 of Test Method D 2487).

3.1.1.3 *gravel*—particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

coarse—passes a 3-in. (75-mm) sieve and is retained on a 3/4-in. (19-mm) sieve.

fine—passes a 3/4-in. (19-mm) sieve and is retained on a No. 4 (4.75-mm) sieve.

3.1.1.4 *organic clay*—a clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay, except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.1.5 *organic silt*—a silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.1.6 *peat*—a soil composed primarily of vegetable tissue in various stages of decomposition usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

3.1.1.7 *sand*—particles of rock that will pass a No. 4

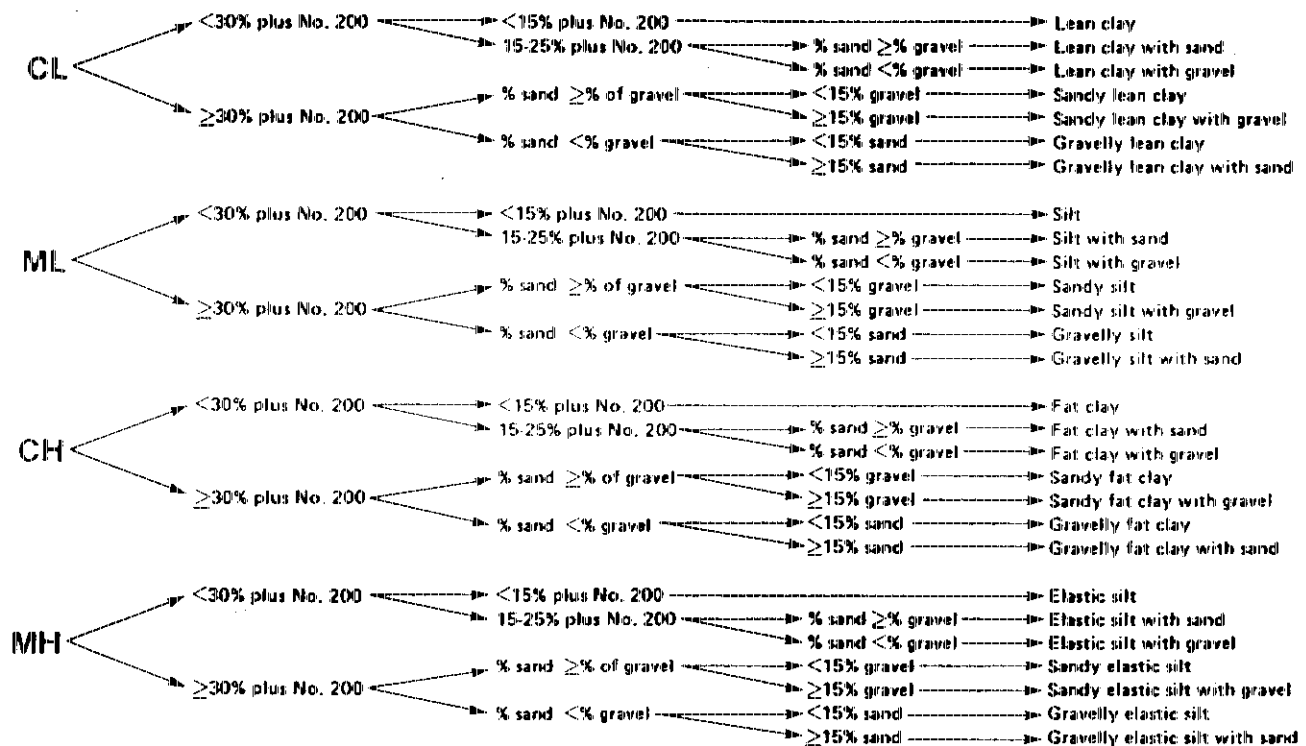
¹ This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

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² Annual Book of ASTM Standards, Vol 04.08.

GROUP SYMBOL

GROUP NAME



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1a Flow Chart for Identifying Inorganic Fine-Grained Soil (50 % or more fines)

(4.75-mm) sieve and be retained on a No. 200 (75-μm) sieve with the following subdivisions:

coarse—passes a No. 4 (4.75-mm) sieve and is retained on a No. 10 (2.00-mm) sieve.

medium—passes a No. 10 (2.00-mm) sieve and is retained on a No. 40 (425-μm) sieve.

fine—passes a No. 40 (425-μm) sieve and is retained on a No. 200 (75-μm) sieve.

3.1.1.8 *silt*—soil passing a No. 200 (75-μm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less than 4, or the plot of plasticity index versus liquid limit falls below the "A" line (see Fig. 3 of Test Method D 2487).

4. Summary of Practice

4.1 Using visual examination and simple manual tests, this practice gives standardized criteria and procedures for describing and identifying soils.

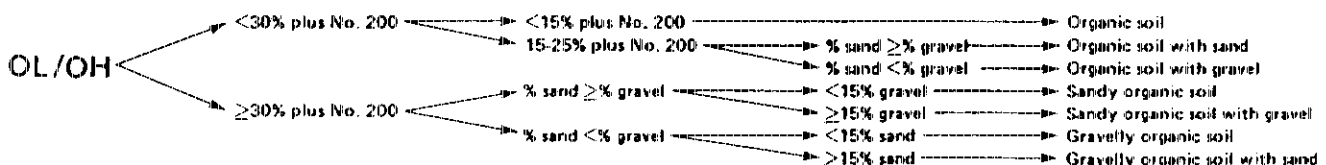
4.2 The soil can be given an identification by assigning a group symbol(s) and name. The flow charts, Figs. 1a and 1b for fine-grained soils, and Fig. 2, for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name. If the soil has properties which do not distinctly place it into a specific group, borderline symbols may be used, see Appendix X3.

NOTE 3—It is suggested that a distinction be made between *dual symbols* and *borderline symbols*.

Dual Symbol—A dual symbol is two symbols separated by a hyphen, for example, GP-GM, SW-SC, CL-ML used to indicate that the soil has been identified as having the properties of a classification in accordance with Test Method D 2487 where two symbols are required. Two symbols are required when the soil has between 5 and 12 % fines or

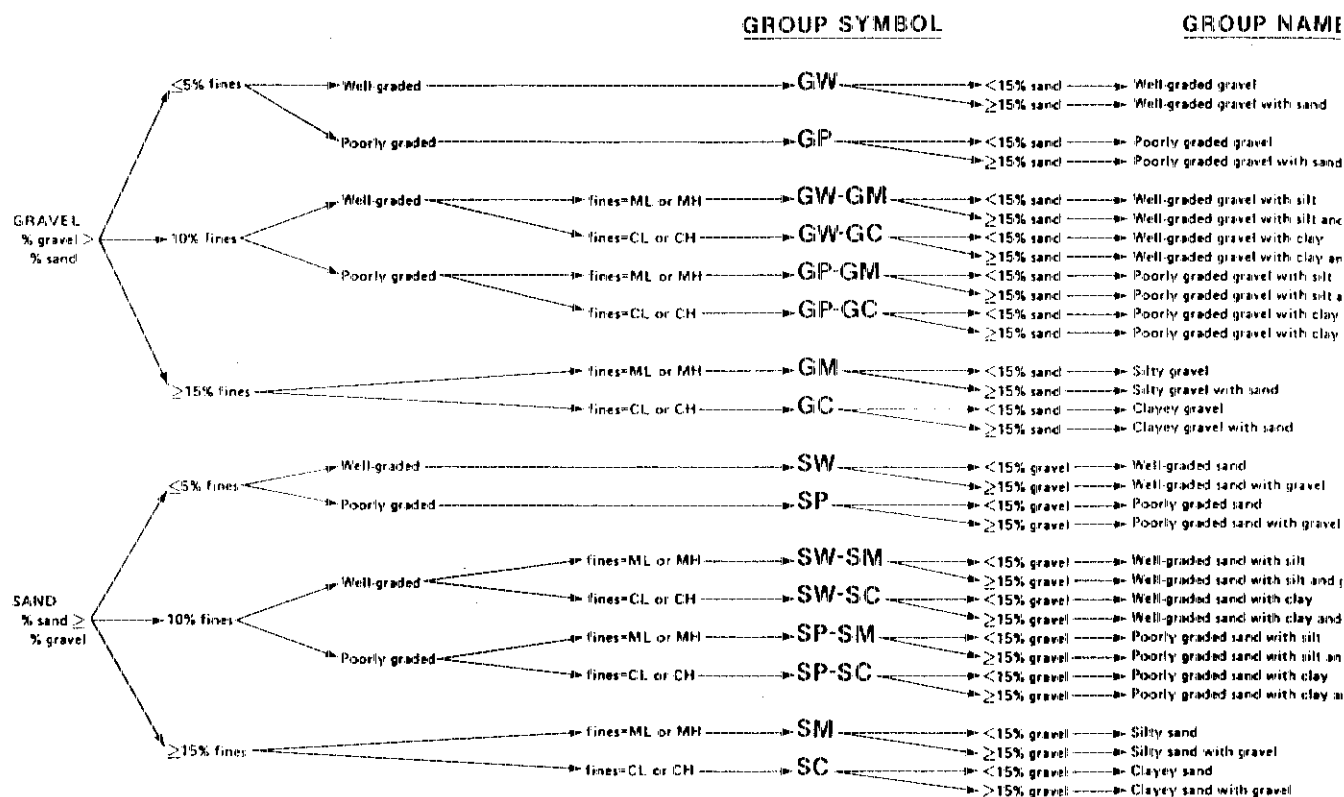
GROUP SYMBOL

GROUP NAME



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1b Flow Chart for Identifying Organic Fine-Grained Soil (50 % or more fines)



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 2 Flow Chart for Identifying Coarse-Grained Soils (less than 50 % fines)

when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

Borderline Symbol—A borderline symbol is two symbols separated by a slash, for example, CL/CH, GM/SM, CL/ML. A borderline symbol should be used to indicate that the soil has been identified as having properties that do not distinctly place the soil into a specific group (see Appendix X3).

5. Significance and Use

5.1 The descriptive information required in this practice can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

5.2 The descriptive information required in this practice should be used to supplement the classification of a soil as determined by Test Method D 2487.

5.3 This practice may be used in identifying soils using the classification group symbols and names as prescribed in Test Method D 2487. Since the names and symbols used in this practice to identify the soils are the same as those used in Test Method D 2487, it shall be clearly stated in reports and all other appropriate documents, that the classification symbol and name are based on visual-manual procedures.

5.4 This practice is to be used not only for identification of soils in the field, but also in the office, laboratory, or wherever soil samples are inspected and described.

5.5 This practice has particular value in grouping similar soil samples so that only a minimum number of laboratory tests need be run for positive soil classification.

NOTE 4—The ability to describe and identify soils correctly is learned more readily under the guidance of experienced personnel, but it may also be acquired systematically by comparing numerical laboratory test

results for typical soils of each type with their visual and characteristics.

5.6 When describing and identifying soil samples from given boring, test pit, or group of borings or pits, it is necessary to follow all of the procedures in this practice every sample. Soils which appear to be similar can be grouped together; one sample completely described can be identified with the others referred to as similar based on performing only a few of the descriptive and identification procedures described in this practice.

5.7 This practice may be used in combination with Practice D 4083 when working with frozen soils.

6. Apparatus

6.1 Required Apparatus:

6.1.1 Pocket Knife or Small Spatula.

6.2 Useful Auxiliary Apparatus:

6.2.1 Small Test Tube and Stopper (or jar with a lid)

6.2.2 Small Hand Lens.

7. Reagents

7.1 **Purity of Water**—Unless otherwise indicated, references to water shall be understood to mean water from a water supply or natural source, including non-potable water.

7.2 **Hydrochloric Acid**—A small bottle of dilute hydrochloric acid, HCl, one part HCl (10 N) to three parts water (This reagent is optional for use with this practice). See Section 8.

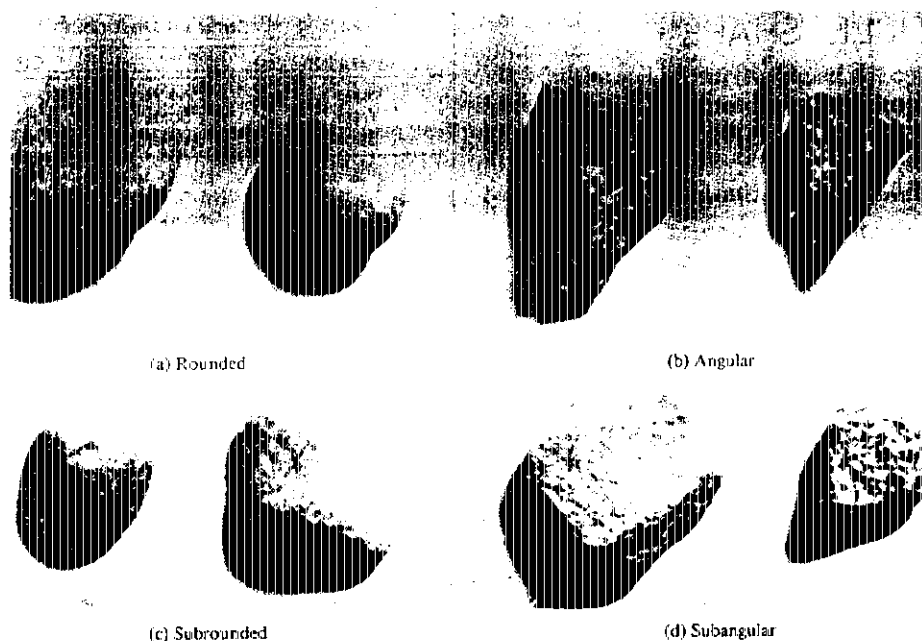


FIG. 3 Typical Angularity of Bulky Grains

8. Safety Precautions

8.1 When preparing the dilute HCl solution of one part concentrated hydrochloric acid (10 N) to three parts of distilled water, slowly add acid into water following necessary safety precautions. Handle with caution and store safely. If solution comes into contact with the skin, rinse thoroughly with water.

8.2 Caution—Do not add water to acid.

9. Sampling

9.1 The sample shall be considered to be representative of the stratum from which it was obtained by an appropriate, accepted, or standard procedure.

NOTE 5—Preferably, the sampling procedure should be identified as having been conducted in accordance with Practices D 1452, D 1587, or D 2113, or Method D 1586.

9.2 The sample shall be carefully identified as to origin.

NOTE 6—Remarks as to the origin may take the form of a boring number and sample number in conjunction with a job number, a geologic stratum, a pedologic horizon or a location description with respect to a permanent monument, a grid system or a station number and offset with respect to a stated centerline and a depth or elevation.

9.3 For accurate description and identification, the minimum amount of the specimen to be examined shall be in

accordance with the following schedule:

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, Dry Weight
4.75 mm (No. 4)	100 g (0.25 lb)
9.5 mm (3/8 in.)	200 g (0.5 lb)
19.0 mm (3/4 in.)	1.0 kg (2.2 lb)
38.1 mm (1 1/2 in.)	8.0 kg (18 lb)
75.0 mm (3 in.)	60.0 kg (132 lb)

NOTE 7—If random isolated particles are encountered that are significantly larger than the particles in the soil matrix, the soil matrix can be accurately described and identified in accordance with the preceding schedule.

9.4 If the field sample or specimen being examined is smaller than the minimum recommended amount, the report shall include an appropriate remark.

10. Descriptive Information for Soils

10.1 *Angularity*—Describe the angularity of the sand (coarse sizes only), gravel, cobbles, and boulders, as angular, subangular, subrounded, or rounded in accordance with the criteria in Table 1 and Fig. 3. A range of angularity may be stated, such as: subrounded to rounded.

10.2 *Shape*—Describe the shape of the gravel, cobbles, and boulders as flat, elongated, or flat and elongated if they meet the criteria in Table 2 and Fig. 4. Otherwise, do not mention the shape. Indicate the fraction of the particles that have the shape, such as: one-third of the gravel particles are flat.

10.3 *Color*—Describe the color. Color is an important property in identifying organic soils, and within a given

TABLE 1 Criteria for Describing Angularity of Coarse-Grained Particles (see Fig. 3)

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

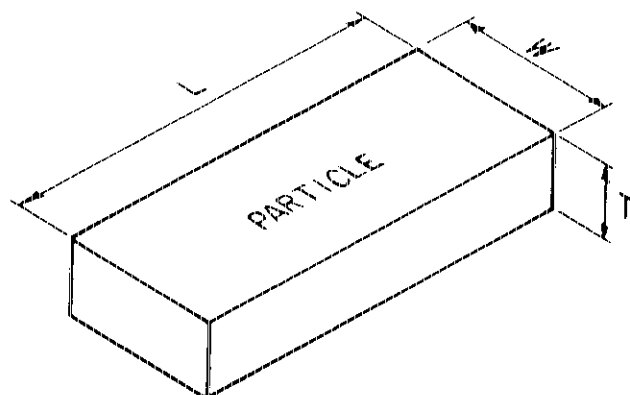
TABLE 2 Criteria for Describing Particle Shape (see Fig. 4)

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

PARTICLE SHAPE

W = WIDTH
T = THICKNESS
L = LENGTH



FLAT: $W/T > 3$
ELONGATED: $L/W > 3$
FLAT AND ELONGATED:
- meets both criteria

FIG. 4 Criteria for Particle Shape

TABLE 3 Criteria for Describing Moisture Condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

locality it may also be useful in identifying materials of similar geologic origin. If the sample contains layers or patches of varying colors, this shall be noted and all representative colors shall be described. The color shall be described for moist samples. If the color represents a dry condition, this shall be stated in the report.

10.4 *Odor*—Describe the odor if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples, but if the samples are dried, the odor may often be revived by heating a moistened sample. If the odor is unusual (petroleum product, chemical, and the like), it shall be described.

10.5 *Moisture Condition*—Describe the moisture condition as dry, moist, or wet, in accordance with the criteria in Table 3.

10.6 *HCl Reaction*—Describe the reaction with HCl as none, weak, or strong, in accordance with the criteria in Table 4. Since calcium carbonate is a common cementing agent, a report of its presence on the basis of the reaction with dilute hydrochloric acid is important.

TABLE 4 Criteria for Describing the Reaction With HCl

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

TABLE 5 Criteria for Describing Consistency

Description	Criteria
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about 1/4 in. (6 mm)
Hard	Thumb will not indent soil but readily indented with thumb
Very hard	Thumbnail will not indent soil

10.7 *Consistency*—For intact fine-grained soil, describe the consistency as very soft, soft, firm, hard, or very hard, in accordance with the criteria in Table 5. This observation is inappropriate for soils with significant amounts of gravel.

10.8 *Cementation*—Describe the cementation of intact coarse-grained soils as weak, moderate, or strong, in accordance with the criteria in Table 6.

10.9 *Structure*—Describe the structure of intact soils in accordance with the criteria in Table 7.

10.10 *Range of Particle Sizes*—For gravel and sand components, describe the range of particle sizes within each component as defined in 3.1.2 and 3.1.6. For example, about 20 % fine to coarse gravel, about 40 % fine to coarse sand.

10.11 *Maximum Particle Size*—Describe the maximum particle size found in the sample in accordance with the following information:

10.11.1 *Sand Size*—If the maximum particle size is sand size, describe as fine, medium, or coarse as defined in 3.1.6. For example: maximum particle size, medium sand.

10.11.2 *Gravel Size*—If the maximum particle size is gravel size, describe the maximum particle size as the smallest sieve opening that the particle will pass. For example, maximum particle size, 1 1/2 in. (will pass a 1 1/2-in. square opening but not a 3/4-in. square opening).

10.11.3 *Cobble or Boulder Size*—If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle. For example: maximum dimension, 18 in. (450 mm).

10.12 *Hardness*—Describe the hardness of coarse sand and larger particles as hard, or state what happens when the particles are hit by a hammer, for example, gravel-size particles fracture with considerable hammer blow, some gravel-size particles crumble with hammer blow. "Hard" means particles do not crack, fracture, or crumble under hammer blow.

10.13 Additional comments shall be noted, such as the presence of roots or root holes, difficulty in drilling or augering hole, caving of trench or hole, or the presence of mica.

10.14 A local or commercial name or a geologic interpretation.

TABLE 6 Criteria for Describing Cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

TABLE 7 Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Sackensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

tation of the soil, or both, may be added if identified as such.

10.15 A classification or identification of the soil in accordance with other classification systems may be added if identified as such.

11. Identification of Peat

11.1 A sample composed primarily of vegetable tissue in various stages of decomposition that has a fibrous to amorphous texture, usually a dark brown to black color, and an organic odor, shall be designated as a highly organic soil and shall be identified as peat, PT, and not subjected to the identification procedures described hereafter.

12. Preparation for Identification

12.1 The soil identification portion of this practice is based on the portion of the soil sample that will pass a 3-in. (75-mm) sieve. The larger than 3-in. (75-mm) particles must be removed, manually, for a loose sample, or mentally, for an intact sample before classifying the soil.

12.2 Estimate and note the percentage of cobbles and the percentage of boulders. Performed visually, these estimates will be on the basis of volume percentage.

NOTE 8—Since the percentages of the particle-size distribution in Test Method D 2487 are by dry weight, and the estimates of percentages for gravel, sand, and fines in this practice are by dry weight, it is recommended that the report state that the percentages of cobbles and boulders are by volume.

12.3 Of the fraction of the soil smaller than 3 in. (75 mm), estimate and note the percentage, by dry weight, of the gravel, sand, and fines (see Appendix X4 for suggested procedures).

NOTE 9—Since the particle-size components appear visually on the basis of volume, considerable experience is required to estimate the percentages on the basis of dry weight. Frequent comparisons with laboratory particle-size analyses should be made.

12.3.1 The percentages shall be estimated to the closest 5 %. The percentages of gravel, sand, and fines must add up to 100 %.

12.3.2 If one of the components is present but not in sufficient quantity to be considered 5 % of the smaller than 3-in. (75-mm) portion, indicate its presence by the term *trace*, for example, trace of fines. A trace is not to be considered in the total of 100 % for the components.

13. Preliminary Identification

13.1 The soil is *fine grained* if it contains 50 % or more

fines. Follow the procedures for identifying fine-grained soils of Section 14.

13.2 The soil is *coarse grained* if it contains less than 50 % fines. Follow the procedures for identifying coarse-grained soils of Section 15.

14. Procedure for Identifying Fine-Grained Soils

14.1 Select a representative sample of the material for examination. Remove particles larger than the No. 40 sieve (medium sand and larger) until a specimen equivalent to about a handful of material is available. Use this specimen for performing the dry strength, dilatancy, and toughness tests.

14.2 Dry Strength:

14.2.1 From the specimen, select enough material to mold into a ball about 1 in. (25 mm) in diameter. Mold the material until it has the consistency of putty, adding water if necessary.

14.2.2 From the molded material, make at least three test specimens. A test specimen shall be a ball of material about ½ in. (12 mm) in diameter. Allow the test specimens to dry in air, or sun, or by artificial means, as long as the temperature does not exceed 60°C.

14.2.3 If the test specimen contains natural dry lumps, those that are about ½ in. (12 mm) in diameter may be used in place of the molded balls.

NOTE 10—The process of molding and drying usually produces higher strengths than are found in natural dry lumps of soil.

14.2.4 Test the strength of the dry balls or lumps by crushing between the fingers. Note the strength as none, low, medium, high, or very high in accordance with the criteria in Table 8. If natural dry lumps are used, do not use the results of any of the lumps that are found to contain particles of coarse sand.

14.2.5 The presence of high-strength water-soluble cementing materials, such as calcium carbonate, may cause exceptionally high dry strengths. The presence of calcium carbonate can usually be detected from the intensity of the reaction with dilute hydrochloric acid (see 10.6).

14.3 Dilatancy:

14.3.1 From the specimen, select enough material to mold into a ball about ½ in. (12 mm) in diameter. Mold the material, adding water if necessary, until it has a soft, but not sticky, consistency.

14.3.2 Smooth the soil ball in the palm of one hand with the blade of a knife or small spatula. Shake horizontally, striking the side of the hand vigorously against the other hand several times. Note the reaction of water appearing on

TABLE 8 Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface

TABLE 9 Criteria for Describing Dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

TABLE 10 Criteria for Describing Toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

the surface of the soil. Squeeze the sample by closing the hand or pinching the soil between the fingers, and note the reaction as none, slow, or rapid in accordance with the criteria in Table 9. The reaction is the speed with which water appears while shaking, and disappears while squeezing.

14.4 Toughness:

14.4.1 Following the completion of the dilatancy test, the test specimen is shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about $\frac{1}{8}$ in. (3 mm) in diameter. (If the sample is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation.) Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about $\frac{1}{8}$ in. The thread will crumble at a diameter of $\frac{1}{8}$ in. when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

14.4.2 Describe the toughness of the thread and lump as low, medium, or high in accordance with the criteria in Table 10.

14.5 *Plasticity*—On the basis of observations made during the toughness test, describe the plasticity of the material in accordance with the criteria given in Table 11.

14.6 Decide whether the soil is an *inorganic* or an *organic* fine-grained soil (see 14.8). If inorganic, follow the steps given in 14.7.

14.7 Identification of Inorganic Fine-Grained Soils:

TABLE 11 Criteria for Describing Plasticity

Description	Criteria
Nonplastic	A $\frac{1}{8}$ -in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

14.7.1 Identify the soil as a *lean clay*, CL, if the soil has medium to high dry strength, no or slow dilatancy, and medium toughness and plasticity (see Table 12).

14.7.2 Identify the soil as a *fat clay*, CH, if the soil has high to very high dry strength, no dilatancy, and medium toughness and plasticity (see Table 12).

14.7.3 Identify the soil as a *silt*, ML, if the soil has low dry strength, slow to rapid dilatancy, and low toughness and plasticity, or is nonplastic (see Table 12).

14.7.4 Identify the soil as an *elastic silt*, MH, if the soil has low to medium dry strength, no to slow dilatancy, and medium toughness and plasticity (see Table 12).

NOTE 11—These properties are similar to those for a lean clay. However, the silt will dry quickly on the hand and have a smooth feel when dry. Some soils that would classify as MH in accordance with the criteria in Test Method D 2487 are visually difficult to distinguish from lean clays, CL. It may be necessary to perform laboratory tests for proper identification.

14.8 Identification of Organic Fine-Grained Soils:

14.8.1 Identify the soil as an *organic soil*, OL/OH, if the soil contains enough organic particles to influence the physical properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soil changes color, for example, black to brown, when exposed to air. Some organic soils will lighten in color significantly when air dried. Organic soils normally will not have a sandy feel or plasticity. The thread for the toughness test is spongy.

NOTE 12—In some cases, through practice and experience, it may be possible to further identify the organic soils as organic silts or organic clays, OL or OH. Correlations between the dilatancy, dry strength, toughness tests, and laboratory tests can be made to identify organic soils in certain deposits of similar materials of known geologic origin.

14.9 If the soil is estimated to have 15 to 25 % sand, gravel, or both, the words "with sand" or "with gravel" (whichever is more predominant) shall be added to the group name. For example: "lean clay with sand, CL" or "silt with gravel, ML" (see Figs. 1a and 1b). If the percentage of sand is equal to the percentage of gravel, use "with sand."

14.10 If the soil is estimated to have 30 % or more sand, gravel, or both, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if the soil appears to be more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand. For example: "sandy lean clay, CL", "gravelly fat clay, CH", "sandy silt, ML" (see Figs. 1a and 1b). If the percentage of sand is equal to the percent of gravel, use "sandy."

15. Procedure for Identifying Coarse-Grained Soils (Coarse-Grained Soils Contain less than 50 % fines)

15.1 The soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand.

TABLE 12 Identification of Inorganic Fine-Grained Soils from Manual Tests

Soil Symbol	Dry Strength	Dilatancy	Toughness
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High

TABLE 13 Checklist for Description of Soils

1. Group name
2. Group symbol
3. Percent of cobbles or boulders, or both (by volume)
4. Percent of gravel, sand, or fines, or all three (by dry weight)
5. Particle-size range:
Gravel—fine, coarse
Sand—fine, medium, coarse
6. Particle angularity: angular, subangular, subrounded, rounded
7. Particle shape: (if appropriate) flat, elongated, flat and elongated
8. Maximum particle size or dimension
9. Hardness of coarse sand and larger particles
10. Plasticity of fines: nonplastic, low, medium, high
11. Dry strength: none, low, medium, high, very high
12. Dilatancy: none, slow, rapid
13. Toughness: low, medium, high
14. Color (in moist condition)
15. Odor (mention only if organic or unusual)
16. Moisture: dry, moist, wet
17. Reaction with HCl: none, weak, strong
For intact samples:
18. Consistency (fine-grained soils only): very soft, soft, firm, hard, very hard
19. Structure: stratified, laminated, fissured, slickensided, lensed, homogeneous
20. Cementation: weak, moderate, strong
21. Local name
22. Geologic interpretation
23. Additional comments: presence of roots or root holes, presence of mica, gypsum, etc., surface coatings on coarse-grained particles, caving or sloughing of auger hole or trench sides, difficulty in augering or excavating, etc.

reaction with HCl; original field sample had about 5 % (by volume) subrounded cobbles, maximum dimension, 150 mm.

In-Place Conditions—Firm, homogeneous, dry, brown

Geologic Interpretation—Alluvial fan

NOTE 14—Other examples of soil descriptions and identification are given in Appendixes X1 and X2.

NOTE 15—If desired, the percentages of gravel, sand, and fines may be stated in terms indicating a range of percentages, as follows:

Trace—Particles are present but estimated to be less than 5 %

Few—5 to 10 %

Little—15 to 25 %

Some—30 to 45 %

Mostly—50 to 100 %

16.2 If, in the soil description, the soil is identified using a classification group symbol and name as described in Test Method D 2487, it must be distinctly and clearly stated in log forms, summary tables, reports, and the like, that the symbol and name are based on visual-manual procedures.

17. Precision and Bias

17.1 This practice provides qualitative information only, therefore, a precision and bias statement is not applicable.

18. Keywords

18.1 classification; clay; gravel; organic soils; sand; silt; soil classification; soil description; visual classification

15.2 The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage of sand.

15.3 The soil is a *clean gravel* or *clean sand* if the percentage of fines is estimated to be 5 % or less.

15.3.1 Identify the soil as a *well-graded gravel*, GW, or as a *well-graded sand*, SW, if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes.

15.3.2 Identify the soil as a *poorly graded gravel*, GP, or as a *poorly graded sand*, SP, if it consists predominantly of one size (uniformly graded), or it has a wide range of sizes with some intermediate sizes obviously missing (gap or skip graded).

15.4 The soil is either a *gravel with fines* or a *sand with fines* if the percentage of fines is estimated to be 15 % or more.

15.4.1 Identify the soil as a *clayey gravel*, GC, or a *clayey sand*, SC, if the fines are clayey as determined by the procedures in Section 14.

15.4.2 Identify the soil as a *silty gravel*, GM, or a *silty sand*, SM, if the fines are silty as determined by the procedures in Section 14.

15.5 If the soil is estimated to contain 10 % fines, give the soil a dual identification using two group symbols.

15.5.1 The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, SM).

15.5.2 The group name shall correspond to the first group symbol plus the words "with clay" or "with silt" to indicate the plasticity characteristics of the fines. For example: "well-graded gravel with clay, GW-GC" or "poorly graded sand with silt, SP-SM" (see Fig. 2).

15.6 If the specimen is predominantly sand or gravel but contains an estimated 15 % or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example: "poorly graded gravel with sand, GP" or "clayey sand with gravel, SC" (see Fig. 2).

15.7 If the field sample contains any cobbles or boulders, or both, the words "with cobbles" or "with cobbles and boulders" shall be added to the group name. For example: "silty gravel with cobbles, GM."

16. Report

16.1 The report shall include the information as to origin, and the items indicated in Table 13.

NOTE 13—Example: *Clayey Gravel with Sand and Cobbles, GC*—About 50 % fine to coarse, subrounded to subangular gravel; about 30 % fine to coarse, subrounded sand; about 20 % fines with medium plasticity, high dry strength, no dilatancy, medium toughness; weak

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF VISUAL SOIL DESCRIPTIONS

X1.1 The following examples show how the information required in 16.1 can be reported. The information that is included in descriptions should be based on individual circumstances and need.

X1.1.1 *Well-Graded Gravel with Sand (GW)*—About 75 % fine to coarse, hard, subangular gravel; about 25 % fine to coarse, hard, subangular sand; trace of fines; maximum size, 75 mm, brown, dry; no reaction with HCl.

X1.1.2 *Silty Sand with Gravel (SM)*—About 60 % predominantly fine sand; about 25 % silty fines with low plasticity, low dry strength, rapid dilatancy, and low toughness; about 15 % fine, hard, subrounded gravel, a few gravel-size particles fractured with hammer blow; maximum size, 25 mm; no reaction with HCl (Note—Field sample size smaller than recommended).

In-Place Conditions—Firm, stratified and contains lenses of silt 1 to 2 in. (25 to 50 mm) thick, moist, brown to gray;

in-place density 106 lb/ft³; in-place moisture 9 %.

X1.1.3 *Organic Soil (OL/OH)*—About 100 % fine to coarse, low plasticity, slow dilatancy, low dry strength, low toughness; wet, dark brown, organic odor; weak reaction with HCl.

X1.1.4 *Silty Sand with Organic Fines (SM)*—About 60 % fine to coarse, hard, subangular reddish sand; about 25 % organic and silty dark brown nonplastic fines with low strength and slow dilatancy; wet; maximum size, 25 mm; weak reaction with HCl.

X1.1.5 *Poorly Graded Gravel with Silt, Sand, Cobble and Boulders (GP-GM)*—About 75 % fine to coarse subrounded to subangular gravel; about 15 % fine to medium sand; about 10 % silty sand; about 5 % moist, brown; no reaction with HCl; origin sample had about 5 % (by volume) hard, subrounded cobbles and a trace of hard, subrounded boulders, maximum dimension of 18 in. (450 mm).

X2. USING THE IDENTIFICATION PROCEDURE AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SANDSTONE, SILTSTONE, MUDSTONE, AND THE LIKE

X2.1 The identification procedure may be used as a descriptive system applied to materials that exist in-situ as shale, claystone, sandstone, siltstone, mudstone, etc., but convert to soils after field or laboratory processing (crushing, slaking, and the like).

X2.2 Materials such as shells, crushed rock, slag, and the like, should be identified as such. However, the procedures used in this practice for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, an identification using a group name and symbol according to this practice may be assigned to aid in describing the material.

X2.3 The group symbol(s) and group names should be placed in quotation marks or noted with some type of distinguishing symbol. See examples.

X2.4 Examples of how group names and symbols can be incorporated into a descriptive system for materials that are not naturally occurring soils are as follows:

X2.4.1 *Shale Chunks*—Retrieved as 2 to 4-in. (50 to

100-mm) pieces of shale from power auger hole, dry, no reaction with HCl. After slaking in water for 24 h, material identified as "Sandy Lean Clay (CL)"; about 70 % fine to medium plasticity, high dry strength, no dilatancy, and medium toughness; about 35 % fine to medium sand; about 5 % gravel-size pieces of shale.

X2.4.2 *Crushed Sandstone*—Product of commercial crushing operation; "Poorly Graded Sand with Silty Sand (SM)"; about 90 % fine to medium sand; about 10 % nonplastic fines; dry, reddish-brown, strong reaction with HCl.

X2.4.3 *Broken Shells*—About 60 % gravel-size broken shells; about 30 % sand and sand-size shell pieces; about 10 % fines; "Poorly Graded Gravel with Sand (GP)."

X2.4.4 *Crushed Rock*—Processed from gravel and boulders in Pit No. 7; "Poorly Graded Gravel (GP)"; about 70 % fine, hard, angular gravel-size particles; about 10 % coarse, hard, angular sand-size particles; dry, tan; no reaction with HCl.

X3. SUGGESTED PROCEDURE FOR USING A BORDERLINE SYMBOL FOR SOILS WITH TWO POSSIBLE IDENTIFICATIONS.

X3.1 Since this practice is based on estimates of particle size distribution and plasticity characteristics, it may be difficult to clearly identify the soil as belonging to one category. To indicate that the soil may fall into one of two

possible basic groups, a borderline symbol may be used consisting of the two symbols separated by a slash. For example: SC/CL.

X3.1.1 A borderline symbol may be used when

ntage of fines is estimated to be between 45 and 55 %. symbol should be for a coarse-grained soil with fines he other for a fine-grained soil. For example: GM/ML /SC.

1.2 A borderline symbol may be used when the ntage of sand and the percentage of gravel are estimated about the same. For example: GP/SP, SC/GC, GM/ It is practically impossible to have a soil that would have derline symbol of GW/SW.

1.3 A borderline symbol may be used when the soil t be either well graded or poorly graded. For example: GP, SW/SP.

1.4 A borderline symbol may be used when the soil eather be a silt or a clay. For example: CL/ML, MH, SC/SM.

1.5 A borderline symbol may be used when a fine-

grained soil has properties that indicate that it is at the boundary between a soil of low compressibility and a soil of high compressibility. For example: CL/CH, MH/ML.

X3.2 The order of the borderline symbols should reflect similarity to surrounding or adjacent soils. For example: soils in a borrow area have been identified as CH. One sample is considered to have a borderline symbol of CL and CH. To show similarity, the borderline symbol should be CH/CL.

X3.3 The group name for a soil with a borderline symbol should be the group name for the first symbol, except for:

CL/CH lean to fat clay
ML/CL clayey silt
CL/ML silty clay

X3.4 The use of a borderline symbol should not be used indiscriminately. Every effort shall be made to first place the soil into a single group.

X4. SUGGESTED PROCEDURES FOR ESTIMATING THE PERCENTAGES OF GRAVEL, SAND, AND FINES IN A SOIL SAMPLE

4.1 *Jar Method*—The relative percentage of coarse- and grained material may be estimated by thoroughly ng a mixture of soil and water in a test tube or jar, and allowing the mixture to settle. The coarse particles will o the bottom and successively finer particles will be sited with increasing time; the sand sizes will fall out of nsion in 20 to 30 s. The relative proportions can be ated from the relative volume of each size separate. method should be correlated to particle-size laboratory minations.

4.2 *Visual Method*—Mentally visualize the gravel size les placed in a sack (or other container) or sacks. Then, e same with the sand size particles and the fines. Then, ally compare the number of sacks to estimate the ntage of plus No. 4 sieve size and minus No. 4 sieve size

present. The percentages of sand and fines in the minus sieve size No. 4 material can then be estimated from the wash test (X4.3).

X4.3 *Wash Test (for relative percentages of sand and fines)*—Select and moisten enough minus No. 4 sieve size material to form a 1-in (25-mm) cube of soil. Cut the cube in half, set one-half to the side, and place the other half in a small dish. Wash and decant the fines out of the material in the dish until the wash water is clear and then compare the two samples and estimate the percentage of sand and fines. Remember that the percentage is based on weight, not volume. However, the volume comparison will provide a reasonable indication of grain size percentages.

X4.3.1 While washing, it may be necessary to break down lumps of fines with the finger to get the correct percentages.

X5. ABBREVIATED SOIL CLASSIFICATION SYMBOLS

5.1 In some cases, because of lack of space, an abbrevi-system may be useful to indicate the soil classification ol and name. Examples of such cases would be graph-ogs, databases, tables, etc.

5.2 This abbreviated system is not a substitute for the ame and descriptive information but can be used in lementary presentations when the complete description erenced.

5.3 The abbreviated system should consist of the soil ification symbol based on this standard with appropriate r case letter prefixes and suffixes as:

<i>Prefix:</i>	<i>Suffix:</i>
s = sandy	s = with sand
g = gravelly	g = with gravel
	c = with cobbles
	b = with boulders

X5.4 The soil classification symbol is to be enclosed in parenthesis. Some examples would be:

<i>Group Symbol and Full Name</i>	<i>Abbreviated</i>
CL, Sandy lean clay	s(CL)
SP-SM, Poorly graded sand with silt and gravel	(SP-SM)g
GP, poorly graded gravel with sand, cobbles, and boulders	(GP)scb
ML, gravelly silt with sand and cobbles	g(ML)sc

X6. RATIONALE

Changes in this version from the previous version, Classification Symbols.
D 2488 - 90, include the addition of X5 on Abbreviated Soil

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.



Standard Test Method for One-Dimensional Consolidation Properties of Soils¹

This standard is issued under the fixed designation D 2435; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers procedures for determining the magnitude and rate of consolidation of soil when it is restrained laterally and drained axially while subjected to incrementally applied controlled-stress loading. Two alternative procedures are provided as follows:

1.1.1 *Test Method A*—This test method is performed with constant load increment duration of 24 h, or multiples thereof. Time-deformation readings are required on a minimum of two load increments.

1.1.2 *Test Method B*—Time-deformation readings are required on all load increments. Successive load increments are applied after 100 % primary consolidation is reached, or at constant time increments as described in Test Method A.

NOTE 1—The determination of the rate and magnitude of consolidation of soil when it is subjected to controlled-strain loading is covered by Test Method D 4186.

1.2 This test method is most commonly performed on undisturbed samples of fine grained soils naturally sedimented in water, however, the basic test procedure is applicable, as well, to specimens of compacted soils and undisturbed samples of soils formed by other processes such as weathering or chemical alteration. Evaluation techniques specified in this test method are generally applicable to soils naturally sedimented in water. Tests performed on other soils such as compacted and residual (weathered or chemically altered) soils may require special evaluation techniques.

1.3 It shall be the responsibility of the agency requesting this test to specify the magnitude and sequence of each load increment, including the location of a rebound cycle, if required, and, for Test Method A, the load increments for which time-deformation readings are desired.

NOTE 2—Time-deformation readings are required to determine the time for completion of primary consolidation and for evaluating the coefficient of consolidation, c_v . Since c_v varies with stress level and load increment (loading or unloading), the load increments with timed readings must be selected with specific reference to the individual project. Alternatively, the requesting agency may specify Test Method B wherein the time-deformation readings are taken on all load increments.

1.4 The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units are approximate and given for guidance only. Reporting of test results

in units other than SI shall not be regarded as nonconformance with this test method.

1.4.1 In the engineering profession it is customary practice to use, interchangeably, units representing both mass and force, unless dynamic calculations ($F = Ma$) are involved. This implicitly combines two separate systems of units, that is, the absolute system and the gravimetric system. It is scientifically undesirable to combine two separate systems within a single standard. This test method has been written using SI units; however, inch-pound conversions are given in the gravimetric system, where the pound (lbf) represents a unit of force (weight). The use of balances or scales recording pounds of mass (lbm), or the recording of density in lb/ft³ should not be regarded as nonconformance with this test method.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- D 422 Method for Particle-Size Analysis of Soils²
- D 653 Terminology Relating to Soil, Rock, and Contained Fluids²
- D 854 Test Method for Specific Gravity of Soils²
- D 1587 Practice For Thin-Walled Tube Geotechnical Sampling of Soils²
- D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock²
- D 2487 Classification of Soils for Engineering Purposes²
- D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)²
- D 3550 Practice for Ring-Lined Barrel Sampling of Soils²
- D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing or Inspection, or both, of Soil and Rock as Used in Engineering Design and Construction²
- D 4186 Test Method for One-Dimensional Consolidation Properties of Soils Using Controlled-Strain Loading²
- D 4220 Practice for Preserving and Transporting Soil Samples²
- D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils²
- D 4452 Methods for X-Ray Radiography of Soil Samples²

¹ This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of subcommittee D18.05 on Structural Properties of Soil.

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² Annual Book of ASTM Standards, Vol 04.08.

* A Summary of Changes section appears at the end of this test method.

$H_0 = 19.050 \text{ mm}$ $H_p = 8.538 \text{ mm}$

Void Ratio and Strain Information

Load Increment (kPa)	d_f corrected (mm)	$\Sigma \Delta H$ (mm)	$\Sigma \Delta H/H_0$ (%)	H ($H_0 - \Delta H$) (mm)	e ($(H-H_p)/H_p$)
initial	5.3300	0	0	19.0500	1.231
5	5.3012	0.0288	0.15	19.0212	1.228
10	5.2743	0.0557	0.29	18.9943	1.225
20	5.2167	0.1133	0.59	18.9367	1.218
40	5.1161	0.2139	1.12	18.8361	1.206
80	4.9433	0.3867	2.03	18.6633	1.186
160	4.4740	0.8560	4.49	18.1940	1.131
320	2.9804	2.3496	12.33	16.7004	0.956
640	1.8908	3.4392	18.05	15.6108	0.828
1280	0.9860	4.3440	22.80	14.7060	0.722
320	1.0747	4.2553	22.34	14.7947	0.733
80	1.4000	3.9300	20.63	15.1200	0.771
20	1.8169	3.5131	18.44	15.5369	0.820
5	2.2319	3.0981	16.26	15.9519	0.868

Coefficient of Consolidation, c_v

$d_{f,c}$ corrected (mm)	$\Sigma \Delta H$ (mm)	c_{50} (%)	H_{50} (mm)	c_{50}	t_{50} (sec)
5.0604	0.2696	1.42	18.780	1.200	52
4.7945	0.5355	2.81	18.515	1.169	144
3.7861	1.5439	8.10	17.506	1.050	516
2.4983	2.8317	14.86	16.218	0.900	282
1.5077	3.8223	20.06	15.228	0.784	156

FIG. 1 Consolidation Test Summary

D4546 Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils²

3. Terminology

3.1 *Definitions*—The definitions of terms used in this test method shall be in accordance with Terminology D 653.

4. Summary of Test Method

4.1 In this test method a soil specimen is restrained laterally and loaded axially with total stress increments. Each stress increment is maintained until excess pore water pressures are completely dissipated. During the consolidation process, measurements are made of change in the specimen height and these data are used to determine the relationship between the effective stress and void ratio or strain, and the rate at which consolidation can occur by evaluating the coefficient of consolidation.

5. Significance and Use

5.1 The data from the consolidation test are used to estimate the magnitude and rate of both differential and total settlement of a structure or earthfill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

5.2 The test results can be greatly affected by sample disturbance. Careful selection and preparation of test specimens is required to minimize disturbance.

NOTE 3—Notwithstanding the statement on precision and bias contained in this standard, the precision of this test method is dependent on the competence of the personnel performing the test and suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 generally are considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D 3740 does not assure reliable testing. Reliable testing depends on many factors, and Practice D 3740 provides a means of evaluation some of these factors.

5.3 Consolidation test results are dependent upon the magnitude of the load increments. Traditionally, the load is doubled for each increment resulting in a load-increment ratio of 1. For undisturbed samples, this load procedure has

provided data from which estimates of the preconsolidation pressure also referred to as the maximum past pressure established evaluation techniques, compare direct field measurement. Other load schedules may be used to model particular field conditions or meet special requirements. For example, it may be desirable to impose a load increment in accordance with the wetting pattern expected in the field in order to best simulate field response. Smaller than standard load increments may be desirable for soils that are highly sensitive to strain rate. The test method specifies a technique to estimate the preconsolidation pressure. A simple technique to verify that one set of time rate data taken after the preconsolidation pressure. Several evaluation techniques exist and may yield different estimates of the preconsolidation pressure. Therefore, the requesting agency may specify an alternate technique to estimate the preconsolidation pressure.

5.4 Consolidation test results are dependent upon the duration of each load increment. Traditionally, the duration is the same for each increment and equal to the time required for complete consolidation. For some soils, the rate of consolidation is so slow that complete consolidation (dissipation of excess pore water pressure) will require more than 24 h. The apparatus in general does not have provisions for formal verification of pressure dissipation. It is necessary to use an indirect technique which indirectly determines that consolidation is complete. This test method specifies two techniques. However, the requesting agency may specify an alternate technique and still be in conformance with this test method.

5.5 The apparatus in general use for this test method does not have provisions for verification of saturation of undisturbed samples taken from below the water table. However, the time rate of deformation is sensitive to degree of saturation and caution should be exercised regarding estimates for duration of settlement when partially saturated conditions prevail. The degree of partial saturation influences the test results and is a part of the test evaluation and may include theoretical models other than conventional consolidation.

ory. Alternatively, the test may be performed using an apparatus equipped to saturate the specimen.

This test method uses conventional consolidation based on Terzaghi's consolidation equation to compute the coefficient of consolidation, c_v . The analysis is based on the following assumptions:

- 5.6.1 The soil is saturated and has homogeneous properties;
- 5.6.2 The flow of pore water is in the vertical direction;
- 5.6.3 The compressibility of soil particles and pore water negligible compared to the compressibility of the soil skeleton;
- 5.6.4 The stress-strain relationship is linear over the load increment;
- 5.6.5 The ratio of soil permeability to soil compressibility constant over the load increment; and
- 5.6.6 Darcy's law for flow through porous media applies.

Apparatus

6.1 *Load Device*—A suitable device for applying vertical loads or total stresses to the specimen. The device should be capable of maintaining specified loads for long periods of time with an accuracy of $\pm 0.5\%$ of the applied load and should permit quick application of a given load increment without significant impact.

NOTE 4—Load application generally should be completed in a time corresponding to $0.01 t_{100}$ or less. For soils where primary consolidation is completed in 3 min, load application should be less than 2 s.

6.2 *Consolidometer*—A device to hold the specimen in a fixture that is either fixed to the base or floating (supported by a ring on periphery of specimen) with porous disks on each face of the specimen. The inside diameter of the ring shall be determined to a tolerance of 0.075 mm (0.003 in.). The consolidometer shall also provide a means of submerging the specimen, for transmitting the concentric vertical load to the porous disks, and for measuring the change in height of specimen.

6.2.1 *Minimum Specimen Diameter*—The minimum specimen diameter shall be 50 mm (2.00 in.).

6.2.2 *Minimum Specimen Height*—The minimum initial specimen height shall be 12 mm (0.5 in.), but shall be not less than ten times the maximum particle diameter.

NOTE 5—If large particles are found in the specimen after testing, include in the report this visual observation or the results of a particle size analysis in accordance with Method D 422 (except the minimum sample size requirement shall be waived).

6.2.3 *Minimum Specimen Diameter-to-Height Ratio*—The minimum specimen diameter-to-height ratio shall be 2.5.

NOTE 6—The use of greater diameter-to-height ratios is recommended. To minimize the effects of friction between the sides of the specimen and ring, a diameter-to-height ratio greater than four is preferable.

6.2.4 *Specimen Ring Rigidity*—The rigidity of the ring shall be such that, under hydrostatic stress conditions in the specimen, the change in diameter of the ring will not exceed 0.03 % of the diameter under the greatest load applied.

6.2.5 *Specimen Ring Material*—The ring shall be made of a material that is noncorrosive in relation to the soil tested. The inner surface shall be highly polished or shall be coated

with a low-friction material. Silicone grease or molybdenum disulfide is recommended; polytetrafluoroethylene is recommended for nonsandy soils.

6.3 *Porous Disks*—The porous disks shall be of silicon carbide, aluminum oxide, or similar noncorrosive material. The grade of the disks shall be fine enough to prevent intrusion of soil into the pores. If necessary, a filter paper (see Note 7) may be used to prevent intrusion of the soil into the disks; however, the permeability of the disks, and filter paper, if used, must be at least one order of magnitude higher than that of the specimen.

NOTE 7—Whatman No. 54 filter paper has been found to meet requirements for permeability and durability.

6.3.1 *Diameter*—The diameter of the top disk shall be 0.2 to 0.5 mm (0.01 to 0.02 in.) less than the inside diameter of the ring. If a floating ring is used, the bottom disk shall have the same diameter as the top disk.

NOTE 8—The use of tapered disks is recommended, with the larger diameter in contact with the soil.

6.3.2 *Thickness*—Thickness of the disks shall be sufficient to prevent breaking. The top disk shall be loaded through a corrosion-resistant plate of sufficient rigidity to prevent breakage of the disk.

6.3.3 *Maintenance*—The disks shall be clean and free from cracks, chips, and nonuniformities. New porous disks should be boiled for at least 10 minutes and left in the water to cool to ambient temperature before use. Immediately after each use, clean the porous disks with a nonabrasive brush and boil to remove clay particles that may reduce their permeability. It is recommended that porous disks be stored in a jar with deaired water between tests.

6.4 *Specimen Trimming Device*—A trimming turntable or a cylindrical cutting ring may be used for trimming the sample down to the inside diameter of the consolidometer ring with a minimum of disturbance. A cutter having the same inside diameter as the specimen ring shall attach to or be integral with the specimen ring. The cutter shall have a sharp edge, a highly polished surface and be coated with a low-friction material. Alternatively, a turntable or trimming lathe may be used. The cutting tool must be properly aligned to form a specimen of the same diameter as that of the ring.

6.5 *Deformation Indicator*—To measure change in specimen height, with a readability of 0.0025 mm (0.0001 in.).

6.6 *Miscellaneous Equipment*—Including timing device with 1 s readability, distilled or demineralized water, spatulas, knives, and wire saws, used in preparing the specimen.

6.7 *Balances*, in accordance with Method D 2216.

6.8 *Drying Oven*, in accordance with Method D 2216.

6.9 *Water Content Containers*, in accordance with Method D 2216.

6.10 *Environment*—Tests shall be performed in an environment where temperature fluctuations are less than $\pm 4^\circ\text{C}$ ($\pm 7^\circ\text{F}$) and there is no direct exposure to sunlight.

7. Calibration

7.1 The measured vertical deformations must be corrected for apparatus flexibility whenever the calibration correction determined in 7.4 exceeds 5 % of the measured deformation and in all tests where filter paper disks are used.

7.2 Assemble the consolidometer with a copper or hard

steel disk of approximately the same height as the test specimen and 1 mm (0.04 in.) smaller in diameter than the ring, in place of the sample. Moisten the porous disks. If filter papers are to be used (see 6.3), they should be moistened and sufficient time (a minimum of 2 min.) allowed for the moisture to be squeezed from them during each increment of the calibration process.

7.3 Load and unload the consolidometer as in the test and measure the deformation for each load applied. When filter papers are used it is imperative that calibration be performed following the exact loading and unloading schedule to be used. This is due to the inelastic deformation characteristics of filter paper. Recalibration for tests without filter paper need be done only on an annual basis, or after replacement and reassembly of apparatus components.

7.4 At each load applied, plot or tabulate the corrections to be applied to the measured deformation of the test specimen. Note that the metal disk will deform also; however, the correction due to this deformation will be negligible for all but extremely stiff soils. If necessary, the compression of the metal disk can be computed and applied to the corrections.

8. Sampling

8.1 Practices D 1587 and D 3550 cover procedures and apparatus that may be used to obtain undisturbed samples generally satisfactory for testing. Specimens may also be trimmed from large undisturbed block samples fabricated and sealed in the field. Finally, remolded specimens may be prepared from bulk samples to density and moisture conditions stipulated by the agency requesting the test.

8.2 Undisturbed samples destined for testing in accordance with this test method shall be preserved, handled, and transported in accordance with the practices for Group C and D samples in Practices D 4220. Bulk samples for remolded specimens should be handled and transported in accordance with the practice for Group B samples.

8.3 *Storage*—Storage of sealed samples should be such that no moisture is lost during storage, that is, no evidence of partial drying of the ends of the samples or shrinkage. Time of storage should be minimized, particularly when the soil or soil moisture is expected to react with the sample tubes.

8.4 The quality of consolidation test results diminishes greatly with sample disturbance. It should be recognized that no sampling procedure can ensure completely undisturbed samples. Therefore, careful examination of the sample is essential in selection of specimens for testing.

NOTE 9—Examination for sample disturbance, stones, or other inclusions, and selection of specimen location is greatly facilitated by x-ray radiography of the samples (see Methods D 4452).

9. Specimen Preparation

9.1 All possible precautions should be taken to minimize disturbance of the soil or changes in moisture and density during specimen preparation. Avoid vibration, distortion, and compression.

9.2 Prepare test specimens in an environment where soil moisture change during preparation is minimized.

NOTE 10—A high humidity environment is usually used for this purpose.

9.3 Trim the specimen and insert it into the consolidation

ring. When specimens come from undisturbed soil collected using sample tubes, the inside diameter of the tube shall be at least 5 mm (0.25 in.) greater than the inside diameter of the consolidation ring, except as noted in 9.4 and 9.5. It is recommended that either a trimming turntable or a cylindrical cutting ring be used to cut the soil to the proper diameter. When using a trimming turntable, make a complete perimeter cut, reducing the specimen diameter to the inside diameter of the consolidation ring. Carefully insert specimen into the consolidation ring, by the width of the specimen, with a minimum of force. Repeat until the specimen protrudes from the bottom of the ring. When using a cylindrical cutting ring, trim the soil to a gentle taper in front of the cutting edge. After the taper is formed, advance the cutter a small distance to form the final diameter. Repeat the process until the specimen protrudes from the ring.

9.4 Fibrous soils, such as peat, and those soils that are easily damaged by trimming, may be transferred directly from the sampling tube to the ring, provided that the ring has the same diameter as the sample tube.

9.5 Specimens obtained using a ring-lined sampler may be used without prior trimming, provided they comply with the requirements of Practice D 3550 and this test method.

9.6 Trim the specimen flush with the plane ends of the ring. The specimen may be recessed slightly below the top of the ring, to facilitate centering of the top stone, by par extrusion and trimming of the bottom surface. For soft medium soils, a wire saw should be used for trimming the top and bottom of the specimen to minimize smearing. A straightedge with a sharp cutting edge may be used for the final trim after the excess soil has first been removed with a wire saw. For stiff soils, a sharpened straightedge may be used for trimming the top and bottom. If a small amount of soil is encountered in any surface being trimmed, it should be removed and the resulting void filled with soil from the trimmings.

NOTE 11—If, at any stage of the test, the specimen swells beyond its initial height, the requirement of lateral restraint of the soil dictates the use of a recessed specimen or the use of a specimen ring equipped with an extension collar of the same inner diameter as the specimen ring. In no time should the specimen extend beyond the specimen ring extension collar.

9.7 Determine the initial wet mass of the specimen, M , in the consolidation ring by measuring the mass of the ring with specimen and subtracting the tare mass of the ring.

9.8 Determine the initial height, H_o , of the specimen to the nearest 0.025 mm (0.001 in.) by taking the average of at least four evenly spaced measurements over the top and bottom surfaces of the specimen using a dial comparator or other suitable measuring device.

9.9 Compute the initial volume, V_o , of the specimen to the nearest 0.25 cm³ (0.015 in.³) from the diameter of the ring and the initial specimen height.

9.10 Obtain two or three natural water content determinations of the soil in accordance with Method D 2216 from material trimmed adjacent to the test specimen if sufficient material is available.

9.11 When index properties are specified by the requesting agency, store the remaining trimmings taken from around the specimen and determined to be similar to the specimen in a sealed container for determination as described in Section 10.

10. Soil Index Property Determinations

10.1 The determination of index properties is an important adjunct to but not a requirement of the consolidation test. These determinations when specified by the requesting agency should be made on the most representative material possible. When testing uniform materials, all index tests may be performed on adjacent trimmings collected in 9.11. When samples are heterogeneous or trimmings are in short supply, index tests should be performed on material from the test specimen as obtained in 11.6, plus representative trimmings collected in 9.11.

10.2 *Specific Gravity*—The specific gravity shall be determined in accordance with Test Method D 854 on material from the sample as specified in 10.1. The specific gravity from another sample judged to be similar to that of the test specimen may be used for calculation in 12.2.5 whenever an accurate void ratio is not needed.

10.3 *Atterberg Limits*—The liquid limit, plastic limit and plasticity index shall be determined in accordance with Test Method D 4318 using material from the sample as specified in 10.1. Determination of the Atterberg limits are necessary for proper material classification but are not a requirement of this test method.

10.4 *Particle Size Distribution*—The particle size distribution shall be determined in accordance with Method D 422 (except the minimum sample size requirement shall be waived) on a portion of the test specimen as obtained in 11.6. A particle size analysis may be helpful when visual inspection indicates that the specimen contains a substantial fraction of coarse grained material but is not a requirement of this test method.

11. Procedure

11.1 Preparation of the porous disks and other apparatus will depend on the specimen being tested. The consolidometer must be assembled in such a manner as to prevent a change in water content of the specimen. Dry porous disks and filters must be used with dry, highly expansive soils and may be used for all other soils. Damp disks may be used for partially saturated soils. Saturated disks may be used when the specimen is saturated and known to have a low affinity for water. Assemble the ring with specimen, porous disks, filter disks (when needed) and consolidometer. If the specimen will not be inundated shortly after application of the seating load (see 11.2), enclose the consolidometer in a loose fitting plastic or rubber membrane to prevent change in specimen volume due to evaporation.

NOTE 12—In order to meet the stated objectives of this test method, the specimen must not be allowed to swell in excess of its initial height prior to being loaded beyond its preconsolidation pressure. Detailed procedures for the determination of one-dimensional swell or settlement potential of cohesive soils is covered by Test Method D 4546.

11.2 Place the consolidometer in the loading device and apply a seating pressure of 5 kPa (100 lbf/ft²). Immediately after application of the seating load, adjust the deformation

indicator and record the initial zero reading, d_o . If necessary, add additional load to keep the specimen from swelling. Conversely, if it is anticipated that a load of 5 kPa (100 lbf/ft²) will cause significant consolidation of the specimen, reduce the seating pressure to 2 or 3 kPa (about 50 lbf/ft²) or less.

11.3 If the test is performed on an intact specimen that was either saturated under field conditions or obtained below the water table, inundate shortly after application of the seating load. As inundation and specimen wetting occur, increase the load as required to prevent swelling. Record the load required to prevent swelling and the resulting deformation reading. If specimen inundation is to be delayed to simulate specific conditions, then inundation must occur at a pressure that is sufficiently large to prevent swell. In such cases, apply the required load and inundate the specimen. Take time deformation readings during the inundation period as specified in 11.5. In such cases, note in the test report the pressure at inundation and the resulting changes in height.

11.4 The specimen is to be subjected to increments of constant total stress. The duration of each increment shall conform to guidelines specified in 11.5. The specific loading schedule will depend on the purpose of the test, but should conform to the following guidelines. If the slope and shape of a virgin compression curve or determination of the preconsolidation pressure is required, the final pressure shall be equal to or greater than four times the preconsolidation pressure. In the case of overconsolidated clays, a better evaluation of recompression parameters may be obtained by imposing an unload-reload cycle after the preconsolidation pressure has been defined. Details regarding location and extent of an unload-reload cycle is the option of the agency requesting the test (see 1.3), however, unloading shall always span at least two decrements of pressure.

11.4.1 The standard loading schedule shall consist of a load increment ratio (LIR) of one which is obtained by doubling the pressure on the soil to obtain values of approximately 12, 25, 50, 100, 200, etc. kPa (250, 500, 1000, 2000, 4000, etc. lbf/ft²).

11.4.2 The standard rebound or unloading schedule should be selected by halving the pressure on the soil (that is, use the same increments of 11.4.1, but in reverse order). However, if desired, each successive load can be only one-fourth as large as the preceding load, that is, skip a decrement.

11.4.3 An alternative loading, unloading, or reloading schedule may be employed that reproduces the construction stress changes or obtains better definition of some part of the stress deformation (compression) curve, or aids in interpreting the field behavior of the soil.

NOTE 13—Small increments may be desirable on highly compressible specimens or when it is desirable to determine the preconsolidation pressure with more precision. It should be cautioned, however, that load increment ratios less than 0.7 and load increments very close to the preconsolidation pressure may preclude evaluation for the coefficient of consolidation, c_v , and the end-of-primary consolidation as discussed in Section 12.

11.5 Before each pressure increment is applied, record the height or change in height, d_f , of the specimen. Two alternative procedures are available that specify the time sequence of readings and the required minimum load duration. Longer durations are often required during specific load increments to define the slope of the characteristic straight line secondary compression portion of the deformation versus log of time graph. For such increments, sufficient readings should be taken near the end of the pressure increment to define this straight line portion. It is not necessary to increase the duration of other pressure increments during the test.

11.5.1 *Test Method A*—The standard load increment duration shall be 24 h. For at least two load increments, including at least one load increment after the preconsolidation pressure has been exceeded, record the height or change in height, d , at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15 and 30 min, and 1, 2, 4, 8 and 24 h (or 0.09, 0.25, 0.49, 1, 4, 9 min etc. in using 12.3.2 to present time-deformation data), measured from the time of each incremental pressure application. Take sufficient readings near the end of the pressure increment period to verify that primary consolidation is completed. For some soils, a period of more than 24 h may be required to reach the end-of-primary consolidation (as determined in 12.3.1.1 or 12.3.2.3). In such cases, load increment durations greater than 24 h are required. The load increment duration for these tests is usually taken at some multiple of 24 h and should be the standard duration for all load increments of the test. The decision to use a time interval greater than 24 h is usually based on experience with particular types of soils. If, however, there is a question as to whether a 24 h period is adequate, a record of height or change in height with time should be made for the initial load increments in order to verify the adequacy of a 24 h period. Load increment durations other than 24 h shall be noted in the report. For pressure increments where time versus deformation data are not required, leave the load on the specimen for the same length of time as when time versus deformation readings are taken.

11.5.2 *Test Method B*—For each increment, record the height or change in height, d , at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30 min, and 1, 2, 4, 8 and 24 h (or 0.09, 0.25, 0.49, 1, 4, 9, min, etc. if using 12.3.2 to present time deformation data), measured from the time of each incremental pressure application. The standard load increment duration shall exceed the time required for completion of primary consolidation as determined by 12.3.1.1, 12.3.2.3 or a criterion set by the requesting agency. For each increment where it is impossible to verify the end of primary consolidation (for example, low LIR or rapid consolidation), the load increment duration shall be constant and exceed the time required for primary consolidation of an increment applied after the preconsolidation pressure and along the virgin compression curve. Where secondary compression must be evaluated, apply pressures for longer periods. The report shall contain the load increment duration for each increment.

NOTE 14—The suggested time intervals for recording height change in height are for typical soils and load increments. It is desirable to change the reading frequency to improve in the data. More rapid consolidation will require more frequent readings. For most soils, primary consolidation during the first load increment will be complete in less time (typically one-tenth) than would be required for a load increment along the virgin compression curve; however, at very low stresses the rebound time can be longer.

11.6 To minimize swell during disassembly, rebound specimen back to the seating load (5 kPa). Once height changes have ceased (usually overnight), dismantle apparatus after releasing the final small load on the specimen. Remove the specimen and the ring from the consolidometer and any free water from the ring and specimen. Determine the mass of the specimen in the ring and subtract the tare mass of the ring to obtain the final wet specimen mass, M_{Tf} . The most accurate determination of the specimen dry mass and water content is found by drying the entire specimen at the end of the test. If the soil sample is homogeneous and sufficient trimmings are available for the specified index testing (see 9.11), then determine the final water content in accordance with Method D 2216 and dry mass of specimen, M_d , using the entire specimen. If the soil is heterogeneous and more material is required for the specified index testing, determine the final water content, w_f , in accordance with Method D 2216 using a small wedge shaped section of specimen. The remaining undried material should be used for the specified index testing.

12. Calculation

12.1 Calculations as shown are based on the use of metric units. Other units are permissible, provided the appropriate conversion factors are used to maintain consistency throughout the calculations. See 1.4.1 for additional comments on the use of inch-pound units.

12.2 Specimen Properties:

12.2.1 Obtain the dry mass of the total specimen, M_d , by direct measurement or for the case where part of specimen is used for index testing, calculate the dry mass as follows:

$$M_d = \frac{M_{Tf}}{1 + w_f}$$

where:

M_{Tf} = moist mass of total specimen after test, g or Mg, and
 w_f = water content (decimal form) wedge of specimen taken after test.

12.2.2 Calculate the initial and final water content, percent, as follows:

$$\text{initial water content: } w_o = \frac{M_{Ts} - M_d}{M_d} \times 100$$

$$\text{final water content: } w_f = \frac{M_{Tf} - M_d}{M_d} \times 100$$

where:

M_d = dry mass of specimen, g or Mg, and
 M_{Ts} = moist mass of specimen before test, g or Mg.

12.2.3 Calculate the initial dry density of the specimen as follows:

$$\rho_d = \frac{M_d}{V_o}$$

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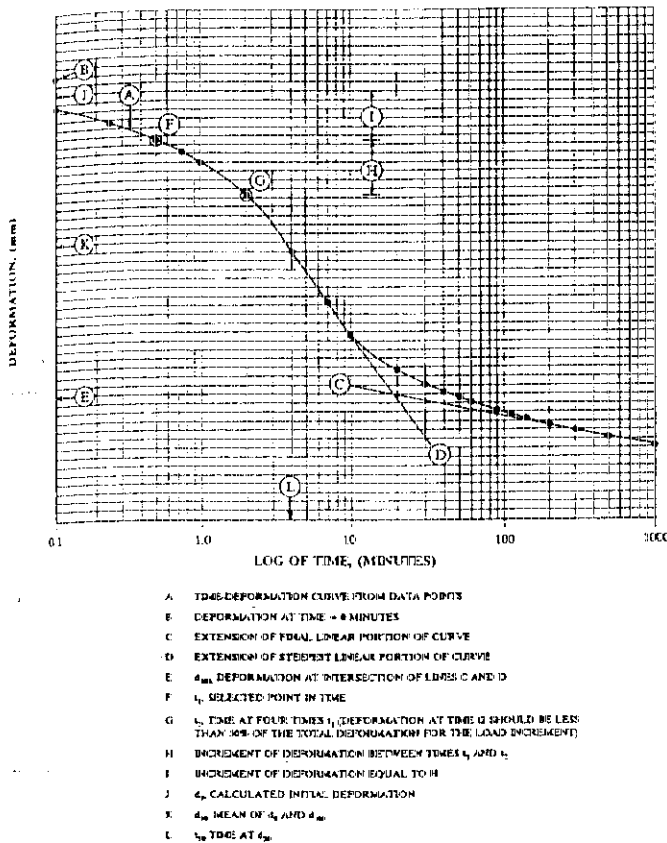


FIG. 2 Time-Deformation Curve From Log of Time Method

where:

ρ_d = dry density of specimen, g/cm³ or Mg/m³, and
 V_o = initial volume of specimen, cm³ or m³.

12.2.4 Calculate the dry unit weight of the specimen as follows:

$$\gamma_d = 9.8 \times \rho_d \text{ in kN/m}^3$$

$$\gamma_d = 62.43 \times \rho_d \text{ in lbf/ft}^3$$

12.2.5 Compute the volume of solids as follows:

$$V_s = \frac{M_d}{G\rho_w}$$

where:

G = specific gravity of the solids, and

ρ_w = density of water, 1.0 g/cm³ or Mg/m³

12.2.6 Since the cross-sectional area of the specimen is constant throughout the test, it is convenient for subsequent calculations to introduce the term "equivalent height of solids," defined as follows:

$$H_s = \frac{V_s}{A}$$

where:

A = specimen area, cm² or m².

12.2.7 Calculate void ratio before and after test as follows:

$$\text{void ratio before test: } e_o = \frac{H_o - H_s}{H_s}$$

$$\text{void ratio after test: } e_f = \frac{H_f - H_s}{H_s}$$

where:

H_o = initial specimen height, cm or m, and

H_f = final specimen height, cm or m.

12.2.8 Calculate the degree of saturation, in percent, before and after test as follows:

$$\text{initial degree of saturation: } S_o = \frac{M_{T_o} - M_d}{A\rho_w(H_o - H_s)} \times 100$$

$$\text{final degree of saturation: } S_f = \frac{M_{T_f} - M_d}{A\rho_w(H_f - H_s)} \times 100$$

12.3 Time-Deformation Properties—From those increments of load where time-deformation readings are obtained, two alternative procedures (see 12.3.1 or 12.3.2) are provided to present the data, determine the end-of-primary consolidation and compute the rate of consolidation. Alternatively, the requesting agency may specify a method of its choice and still be in conformance with this test method. The deformation readings may be presented as measured deformation, deformation corrected for apparatus compressibility or converted to strain (see 12.4).

12.3.1 Referring to Fig. 2, plot the deformation readings, d , versus the log of time (normally in minutes) for each increment of load.

12.3.1.1 First draw a straight line through the points representing the final readings which exhibit a straight line trend and constant slope (C). Draw a second straight line tangent to the steepest part of the deformation-log time curve (D). The intersection represents the deformation, d_{100} , and time, t_{100} , corresponding to 100 % primary consolidation (E). Compression in excess of the above estimated 100 % primary consolidation is defined as secondary compression.

12.3.1.2 Find the deformation representing 0 % primary consolidation by selecting any two points that have a time ratio of 1 to 4. The deformation at the larger of the two times should be greater than 1/4, but less than 1/2 of the total deformation for the load increment. The deformation corresponding to 0 % primary consolidation is equal to the deformation at the smaller time, less the difference in deformation for the two selected times.

12.3.1.3 The deformation, d_{50} , corresponding to 50 % primary consolidation is equal to the average of the deformations corresponding to the 0 and 100 % deformations. The time, t_{50} , required for 50 % consolidation may be found graphically from the deformation-log time curve by observing the time that corresponds to 50 % of the primary consolidation on the curve.

12.3.2 Referring to Fig. 3, plot the deformation readings, d , versus the square root of time (normally in minutes) for each increment of load.

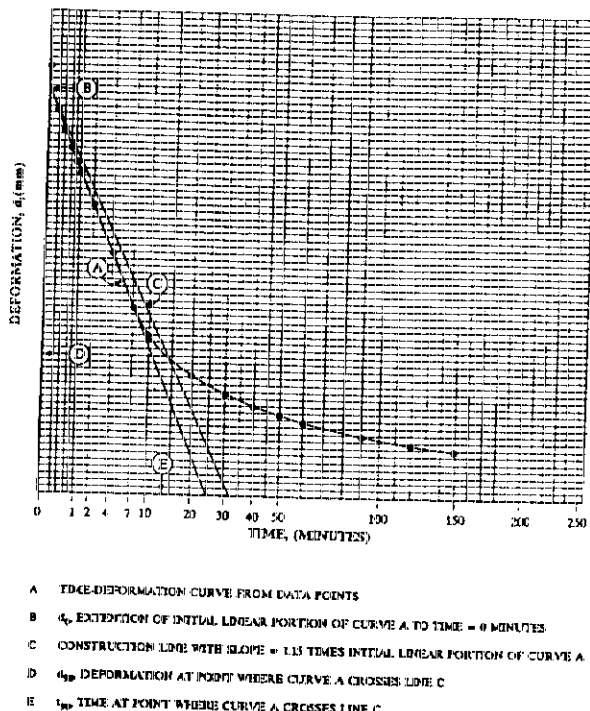


FIG. 3 Time-Deformation Curve From Square Root of Time Method

12.3.2.1 First draw a straight line through the points representing the initial readings that exhibit a straight line trend. Extrapolate the line back to $t = 0$ and obtain the deformation ordinate representing 0 % primary consolidation.

12.3.2.2 Draw a second straight line through the 0 % ordinate so that the abscissa of this line is 1.15 times the abscissa of the first straight line through the data. The intersection of this second line with the deformation-square root of time curve is the deformation, d_{90} , and time, t_{90} , corresponding to 90 % primary consolidation.

12.3.2.3 The deformation at 100 % consolidation is $\frac{1}{2}$ more than the difference in deformation between 0 and 90 % consolidation. The time of primary consolidation, t_{100} , may be taken at the intersection of the deformation-square root of time curve and this deformation ordinate. The deformation, d_{50} , corresponding to 50 % consolidation is equal to the deformation at $\frac{1}{2}$ of the difference between 0 and 90 % consolidation.

12.3.3 Compute the coefficient of consolidation for each increment of load using the following equation and values appropriate to the chosen method of interpretation:

$$c_v = \frac{TH^2_{D_{50}}}{t}$$

where:

T = a dimensionless time factor:

for method 12.3.1 use 50 % consolidation with $T = T_{50} = 0.197$,
for method 12.3.2 use 90 % consolidation with $T = T_{90} = 0.848$,

t = time corresponding to the particular degree of consolidation, s or min;

for method 12.3.1 use $t = t_{50}$,

for method 12.3.2 use $t = t_{90}$, and

$H_{D_{50}}$ = length of the drainage path at 50 % consolidation, cm or m

for double-sided drainage $H_{D_{50}}$ is half the specimen height at the appropriate increment and for one-sided drainage $H_{D_{50}}$ is the full specimen height.

12.4 Load-Deformation Properties:

12.4.1 Tabulate the deformation or change in deformation, d_f , readings corresponding to the end of each increment and, if using Test Method B, corresponding to the end-of-primary consolidation, d_{100} .

12.4.2 Calculate the change in height, $\Delta H = d - d_0$, relative to the initial specimen height for each reading. If necessary, correct the deformation for the apparatus flexibility by subtracting the calibration value obtained in Section 9 from each reading.

12.4.3 Represent the deformation results in one of the following formats.

12.4.3.1 Calculate the void ratio as follows:

$$e = e_0 - \frac{\Delta H}{H_s}$$

12.4.3.2 Alternatively, calculate the vertical strain, in percent, as follows:

$$\epsilon = \frac{\Delta H}{H_0} \times 100$$

12.4.4 Calculate the vertical stress as follows:

$$\sigma_v = \frac{P}{A}$$

where:

P = applied load in N

σ_v = vertical stress in kPa.

12.4.5 Referring to Fig. 4, plot the deformation results (void ratio or strain) corresponding to the end of each increment and, if using Test Method B, corresponding to the end-of-primary consolidation versus the logarithm of the pressure.

NOTE 15—In some cases, it may be preferable to present the load-deformation curve in arithmetic scale.

12.4.6 Referring to Fig. 4, determine the value of the preconsolidation pressure using the following procedure.

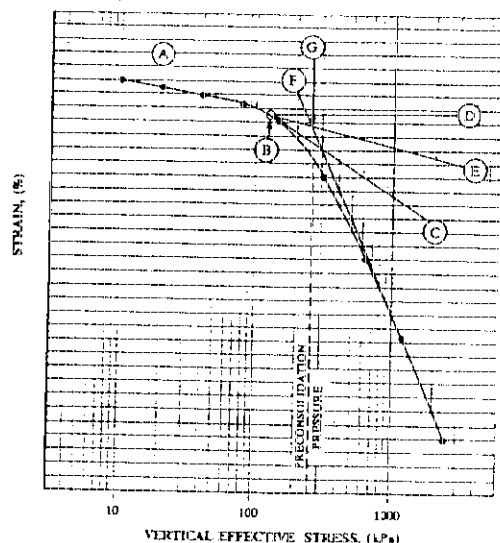
NOTE 16—Any other recognized method of estimating preconsolidation pressure (see references) may also be used, provided the method is identified in the report.

12.4.6.1 Estimate the point of maximum curvature on the consolidation curve (B).

12.4.6.2 Draw the tangent to the consolidation curve at this point (C), and a horizontal line through the point (D), both extended towards increasing values on the abscissa.

12.4.6.3 Draw the line bisecting the angle between these lines (E).

12.4.6.4 Extend the tangent to the steep, linear portion of the consolidation curve (virgin compression branch) (F) upwards to intersection with the bisector line (E).



- A STRESS-STRAIN CURVE FROM DATA POINTS
- B POINT OF MAXIMUM CURVATURE
- C TANGENT LINE TO CURVE AT POINT B
- D HORIZONTAL LINE THROUGH POINT B
- E LINE BISECTING ANGLE BETWEEN LINES C AND D
- F TANGENT TO LINEAR PORTION OF CURVE IN VIRGIN COMPRESSION RANGE
- G INTERSECTION OF LINES E AND F (VERTICAL EFFECTIVE STRESS AT POINT G EQUALS THE PRECONSOLIDATION PRESSURE)

FIG. 4 Evaluation for Preconsolidation Pressure From Casagrande Method

pressure (G) (abscissa) corresponding to this point of intersection is the estimated preconsolidation pressure.

12.4.7 Complete evaluation often includes consideration of information not generally available to the laboratory performing the test. For this reason further evaluation of the test is not mandatory. Many recognized methods of evaluation are described in the literature. Some of these are discussed in the Refs. (1) through (8).³

13. Report

13.1 In addition to project name and location, boring number, sample number, and depth, report the following information.

13.1.1 Description and classification of the soil in accordance with Practice D 2488 or Test Method D 2487 when Atterberg limit data are available. Specific gravity of solids, Atterberg limits and grain size distribution shall also be reported when available plus the source of such information if other than measurements obtained on test specimen. Also note occurrence and approximate size of isolated large particles.

13.1.2 Soil Condition:

13.1.2.1 Average water content of trimmings,

13.1.2.2 Initial and final water content of specimen,

13.1.2.3 Initial and final dry unit weight of specimen,

³The boldface numbers in parentheses refer to a list of references at the end of the text.

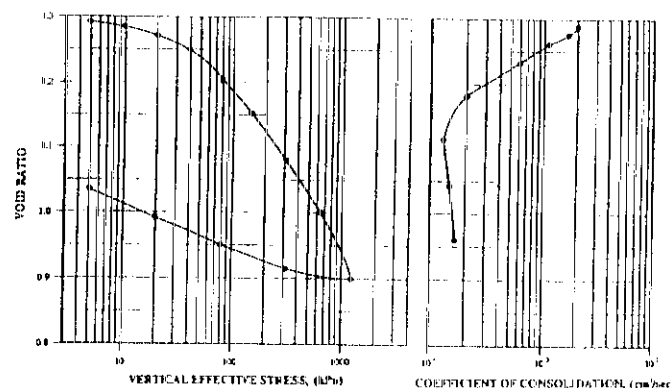


FIG. 5 Example of Consolidation Test Summary Plots

13.1.2.4 Initial and final void ratio of specimen,

13.1.2.5 Initial and final degree of saturation of specimen, and

13.1.2.6 Preconsolidation pressure.

13.1.3 Test Procedure:

13.1.3.1 Preparation procedure used relative to trimming; state whether the specimen was trimmed using a trimming turntable, trimmed using a cutting shoe, or tested directly in a ring from a ring lined sampler.

13.1.3.2 Condition of test (natural moisture or inundated, pressure at inundation).

13.1.3.3 Method of testing (A or B).

13.1.3.4 Test Method used to compute coefficient of consolidation.

13.1.3.5 Listing of loading increments and decrements, and load increment duration, if differing from 24 h; end of increment deformation results and, for Test Method B, end-of-primary deformation results and coefficient of consolidation (see Fig. 1).

13.1.3.6 All departures from the procedure outlined, including special loading sequences.

13.1.4 Graphical Presentations:

13.1.4.1 Graph of deformation versus log time (see Fig. 2) or square root of time (see Fig. 3) for those load increments where time rate readings were taken.

13.1.4.2 Graph of void ratio versus log of pressure curve or percent compression versus log of pressure curve (see Fig. 4).

13.1.4.3 In cases where time rate of deformation readings have been taken for several load increments, prepare a graph of the log of coefficient of consolidation versus average void ratio or average percent compression for the respective load increments (see Fig. 5). Alternatively, a graph of coefficient of consolidation or log of coefficient of consolidation versus log of average pressure may be used. If time rate readings were obtained for only two load increments, simply tabulate the values of c_v versus the average pressure for the increment.

NOTE 17—The average pressure between two load increments is chosen because it is a convenient coordinate for plotting the result. Unless the rate of pore pressure dissipation is measured, it is not possible to determine the actual effective pressure at the time of 50 % consolidation. Furthermore, some ambiguity may arise in cases where the test has been carried through one or more intermediate load-rebound cycles.

14. Precision and Bias

14.1 *Statement of Precision*—Due to the nature of the soil materials tested by this test method it is either not feasible or too costly at this time to produce multiple specimens which have uniform physical properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation. Subcommittee D18.05 welcomes proposals that would allow for development of a valid precision statement.

14.2 *Statement of Bias*—There is no acceptable reference value for this test method, therefore, bias cannot be determined.

15. Keywords

15.1 compressibility; compression curves; consolidation coefficient; consolidation test; consolidation pressure; preconsolidation pressure; primary consolidation; rebound; secondary compression; settlement; swelling

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- (8) Yong, R. N. and Townsend, F. C. Eds. "Consolidation of Soils: Testing and Evaluation," ASTM STP 892, ASTM, 1986.

SUMMARY OF CHANGES

This section identifies the principal changes to this test method that have been incorporated since the last issue.

(1) Practice D 3740 has been added to the Section 2 on Referenced Documents.

(2) A new Note 3 was inserted to Reference D 3740, all subsequent notes have been renumbered.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Attachment A-4

Field Equipment Lists

AR302051

Table 1. Field equipment for groundwater sampling**General Equipment**

Field vehicle
Clipboard
Camera with time/date patch
Color slide film
First-aid kit
Sampling and analysis plan
Site-specific health and safety plan
Health & safety equipment listed in H&S plan
Sample tags and Sharpie pens
Logbook, indelible ink pens
Field Data Forms
Chain-of-custody/Sample analysis request forms
Shipping forms and labels
Chain-of-custody seals
Cellular phone
Rubber boots
Tool kit

Decontamination Equipment

Plastic tubs or coolers
Ten 10-gallon garbage bags
Nitrile gloves
Butyl rubber gloves
Beaker brush
Bristle brush
Water carboys
Deionized water from analytical laboratory
Tap water
Acetone
Hexane
10 percent nitric acid
Liquinox
Plastic squirt bottles
Aluminum foil or untreated butcher paper

Miscellaneous Equipment

Sample packaging materials/bubble wrap
Cellophane tape to cover sample tags
Strapping tape
Duct tape (2 rolls)
Fragile labels (if needed)
Rain gear
Utility knife
Paper towels

Sampling Equipment

Water-level indicator
Teflon bailers (with small and large discharge tubes)
Stainless steel micro-bailer
Nylon cord
Sample bottles
5 Plastic beakers
2 pH/mV meters, 2 pH electrodes
2 bottles electrode filling solution
pH 4.0, 7.0, and 10 calibration buffers
(2 bottles of each buffer)
Specific conductance meter
1,000 and 10,000 μ MHOS/cm standards
(2 each)
Squirt bottle
Peristaltic pump with battery clips
Bennett submersible pump
Teflon-lined bladder pump
Portable generator (110V/220V)
2 plastic buckets, calibrated in 1-L increments.
0.45- μ m filters
Teflon-lined tubing (1/4 in. ID, 3/8 in. thick)
Teflon-lined tubing (1/2 in. ID, 5/8 in. thick)
Black polyethylene tubing
Batteries for meters
Kimwipes
25 ft of silicone tubing
Tape measure (25-ft metal)
50 quart-size Ziploc bags
50 gallon-size Ziploc bags
Ice chest ice or freezable cold packs
Latex gloves
Nitrile gloves
Parafilm
Pliers
Screwdrivers (regular and phillips head)
Turbidity meter (NTU)
Flow-through cell
Dissolved oxygen meter
EMF probe
ZoBell's solution
DR 100
Ferrover iron AccuVacs
Ferrous iron AccuVacs
T-valve
Hose barbs
Wrist watch or stop watch

AR302052

Table 2. Field equipment for solids sampling**General Equipment**

Field vehicle
Clipboard
Camera with time/date patch
Color slide film
First-aid kit
Sampling and analysis plan
Site-specific health and safety plan
Health & safety equipment listed in H&S plan
Sample tags and Sharpie pens
Logbook, indelible ink pens
Chain-of-custody/Sample analysis request forms
Borehole logging forms
Shipping forms and labels
Chain-of-custody seals
Cellular phone
Rubber boots
Tool kit

Decontamination Equipment

Plastic tubs or coolers
Ten 10-gallon garbage bags
Nitrile gloves
Butyl rubber gloves
Beaker brush
Bristle brush
Water carboys
Deionized water from analytical laboratory
Tap water
Methane
10 percent nitric acid
Liquinox
Plastic squirt bottles
Aluminum foil or untreated butcher paper

Miscellaneous Equipment

Sample packaging materials/bubble wrap
Cellophane tape to cover sample tags
Strapping tape
Duct tape (2 rolls)
Rain gear
Utility knife
10-ft. metal tape measure
Paper towels

Sampling Equipment

50 gallon-size Ziploc bags
9 3.5-gallon HDPE buckets with O-ring lids
Ice chest ice or freezable cold packs
Latex gloves
Nitrile gloves
Parafilm
Teflon Tape
Pliers
Screwdrivers (regular and phillips head)
Stainless Steel Spoons
PID
2 in. diameter split core samplers (18 or 24 in. long)
3-in. diameter Shelby tubes (24 in. long)
2-in. diameter plastic end caps
3-in. diameter plastic end caps
2-in. diameter stainless steel core sleeves
Earth Colors soil color chart
Sample bottles
Encore samplers
Sodium bisulfide preservative

AR302053

Attachment A-5

Exponent Standard Operating Procedures

AR302054

STANDARD OPERATING PROCEDURE

MEASUREMENT OF WATER LEVEL ELEVATION AND WELL CASING VOLUME SOP 19

This SOP presents the method to be used to measure water level elevation and well casing volume.

EQUIPMENT REQUIRED

- Electronic water level indicator
- Distilled or deionized water
- Spare batteries.

FIELD PROCEDURES

1. Rinse water level indicator probe and cable with distilled or deionized water.
2. Holding cable reel atop casing, lower indicator probe gradually into well until tone and/or light indicates contact with water surface.
3. Grasp cable exactly at the measuring point marked at the top of the well casing with thumb and index finger. Pull cable out of well slowly to read measurement.
4. Record measured depth to water surface to the nearest 0.01 ft as indicated on graduated cable.
5. Withdraw cable several feet then lower and repeat Steps 2–4. If readings differ by more than 0.2 ft, repeat until readings stabilize.
6. Remove cable and probe from well and rinse with distilled or deionized water.

MAINTENANCE

1. Carry spare batteries for the electronic water level indicator at all times. Weekly during a sample run, check the circuitry of the electronic water level indicator in the field laboratory by assembling the apparatus and dipping the end of the probe into a beaker of water.
2. Clean the probe at the end of each day of sampling by rinsing with tap water and wiping dry with paper towels. In addition, clean probe and cable between wells.

CALCULATIONS

Absolute water level elevation (feet MSL)

$$= \text{Elevation of top of well casing (surveyed)} - \text{average depth to water (from top of well casing reference point)}$$

Volume of water contained in casing (gallons)

$$= (\text{Diameter of well casing [in]}/2)^2 \times .0217 \times (\text{depth to bottom of well [ft]} - \text{depth to water [ft]}) \times 7.48$$

Refer to well construction specifications for depth to bottom of well.

STANDARD OPERATING PROCEDURE

MEASUREMENT OF FIELD PARAMETERS USING A FLOW-THROUGH CELL

SOP 56

This SOP details the procedures for using a flow-through cell for measuring pH, EMF, dissolved oxygen, conductivity, and temperature in the field.

REQUIRED EQUIPMENT

- Flow-through cell
- Flow-through cell repair kit and extra gaskets of multiple sizes
- Tygon® or similar plastic tubing
- Peristaltic pump (or other pump capable of pumping a constant, relatively low flow rate)
- Silicone tubing for the peristaltic pump discharge
- Hose barbs and hose clamps to connect the plastic tubing to the silicone tubing
- pH meter and electrode
- EMF (mV) meter and electrode
- Dissolved oxygen/temperature meter and electrode
- Extra dissolved oxygen probe membrane and filling solution
- Specific conductance/temperature meter and electrode
- Commercial pH buffers (4, 7, and 10)
- ZoBell's solution
- Conductivity standard
- Electrode filling solution (for an Ag/AgCl electrode)
- Platinum electrode polishing paper
- Kimwipes®
- Chart with saturated-air dissolved oxygen concentrations at various temperatures for the elevation of the wells to be sampled
- Deionized water

CALIBRATION AND CARE OF METERS AND ELECTRODES

pH

Inspect the pH electrode to ensure that it is filled with electrode filling solution. The pH meter should be calibrated using two pH buffers that bracket the expected pH of the sample. Follow the manufacturer's instructions for meter calibration. When not in use, the pH electrode should be stored in electrode storage solution. If this is not available, pH 7 buffer solution is acceptable. At no time should the electrode be allowed to dry out.

EMF

Inspect the EMF (mV) probe to ensure that it is filled with electrode filling solution. Rinse the electrode with deionized water and blot dry. Immerse the electrode in ZoBell's solution, and wait for the meter to stabilize. The EMF should be between approximately 200 and 250 mV. Record the EMF in the field logbook. Measure the temperature of the ZoBell's solution (the conductivity meter may be used to measure temperature), and record the temperature in the field logbook.

If the EMF reading is outside the specified range (200--250 mV), clean the electrode by the following procedure. Eject the filling solution from the electrode by pushing the epoxy case toward the top of the electrode; the filling solution will come out the bottom. Rinse the electrode at least twice by filling it and then ejecting the solution. Refill the electrode with filling solution. Rinse the outside of the electrode with deionized water, and measure the EMF of the ZoBell's solution again. If the electrode response is still out of the specified range, carefully clean the platinum disk on the bottom of the electrode with a Kimwipe® or with polishing paper that is provided with the electrode. When the electrode is being transported and stored, the platinum disk should be protected to prevent scratching.

Conductivity

To calibrate the conductivity meter, rinse the probe with conductivity standard, then immerse the probe in the conductivity standard. Measure the temperature and the conductivity of the standard. Record these measurements in the field logbook, along with the expected conductivity of the standard.

Dissolved Oxygen

Inspect the dissolved oxygen probe for integrity. The membrane should be intact and unwrinkled and no air bubbles should be present beneath the membrane. If the membrane integrity has been compromised, replace the membrane following manufacturer's instruc-

tions. When replacing the membrane, it is imperative that no air bubbles are trapped beneath the membrane. Different brands of dissolved oxygen meters are calibrated using different procedures. Refer to the manufacturer's instructions for the specific dissolved oxygen meter being used. Check the calibration by measuring dissolved oxygen in water-saturated air and comparing the measured value against the saturated-air chart for the elevation of the wells to be sampled. The dissolved oxygen probe should be stored in the calibration sleeve, which should always be kept moist. If the calibration sleeve is not available, the probe should be wrapped in a damp paper towel. At no time should the membrane be allowed to dry out.

MEASUREMENT OF FIELD PARAMETERS

1. The well from which samples are taken should be purged (three casing volumes) before measuring field parameters.
2. Calibrate the meters at each well (the dissolved oxygen probe usually only needs to be calibrated once per day), as described above.
3. Insert the probes into the flow-through cell. The gaskets should fit tightly around the probes, and any flow-through cell openings that do not contain a probe should be sealed with a plastic disc. The inflow of the flow-through cell (the flow goes from bottom to top) should be directed so that it passes directly over the dissolved oxygen probe. If the inflow is not directed properly, a piece of Tygon[®] tubing and a wire (a paper clip will work) can be used to direct the flow. Insert the wire into the tubing, and insert the tubing into the inflow opening at the bottom of the flow-through cell. Bend the wire to direct the flow.
4. Connect the outflow from the pump to the bottom of the flow-through cell. Pump water into the flow-through cell until the flow begins exiting through the top. Loosen the fittings around the probes, and bleed all air bubbles out of the flow-through cell.
5. Record the pH, EMF, dissolved oxygen, conductivity, and temperature in the field logbook about every 5 minutes until the readings stabilize.

STANDARD OPERATING PROCEDURE

IRON SPECIATION IN GROUNDWATER

SOP 61

FIELD SAMPLING AND ANALYSIS

1. Collect the groundwater sample using a peristaltic pump, passing the flow through an inline, 0.45- μ m filter and depositing the sample directly into a 300-mL glass beaker.
2. Allow the beaker to overflow twice its volume to avoid oxygenation of the sample.
3. Collect the sample from the bottom of the beaker directly into a HACH Accuvac[®] vial for both Fe⁺² and total iron analyses.
4. Zero the HACH DR100[®] spectrophotometer using groundwater collected from the glass beaker.
5. Calibrate the HACH DR100[®] spectrophotometer by preparing and analyzing standards at 1, 3, and 5 mg/L Fe⁺², in accordance with the manufacturer's operating instructions.
6. Analyze the sample for Fe⁺² and total iron, and record the measurements in the field notebook.

QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance and quality control samples will consist of duplicates and blanks, both collected at a frequency of 1 for every 20 samples.

Note: SOP 19 cited within.

STANDARD OPERATING PROCEDURE

FIELD DETERMINATION OF TRANSMISSIVITY AND HYDRAULIC CONDUCTIVITY USING A SINGLE WELL/PIEZOMETER OR MULTIPLE WELLS AND CONSTANT PUMPING RATE SOP 36

This test procedure is used to estimate the transmissivity of materials surrounding the screen of a monitoring well or piezometer. The hydraulic conductivity of the material can be calculated if the length of the open interval is known. Testing procedures are provided for single well test and multiple well tests (test well and observation wells). The test is performed by pumping the well or piezometer at a constant discharge rate and measuring changes in the water level in the well or piezometer with time and in observation wells located radially around the well. After the pump is shut off, the water level recovery is measured with time in all wells.

APPLICATION

The test method is generally applicable to materials exhibiting moderate to high hydraulic conductivity (i.e., from 10 ft/day to 100 ft/day), unless well yield exceeds the pump capacity.

INTERFERENCES

The accuracy of this test for a single well is affected by the degree that the tested well or piezometer is developed. Tests conducted in poorly developed wells will generally underestimate the value of hydraulic conductivity.

FIELD PROCEDURE

1. If a data logger is being used, install a decontaminated pressure transducer and cable 1 ft above the top of the well screen in the test well and observation wells, as applicable. Ensure that the transducer's

range will cover expected drawdown. If not, raise transducer until expected drawdown is covered by the pressure transducer's range.

2. Install decontaminated pumping system in piezometer or well with intake at least 10 ft below static water level and at least 3 ft above the top of the well screen. If the water level is below the top of the screen or within 5 ft of the top of the screen, install the pump near the bottom of the screen.
3. Install valve (preferably a gate valve) and flow meter system. Ensure that the distance between the flow meter and any bend or constriction in the discharge line is at least 10 times the diameter of the discharge line. Ensure that discharge is directed away from the pumped well.
4. If time allows, determine pumping rate by pumping well beginning at 0.25 gal/minute for 10 minutes, and doubling the discharge rate in steps every 10 minutes. Measure water levels (see SOP 19) with pumping and set valve for rate that brings water level within one-half of available drawdown (static water level minus intake elevation). Otherwise, set initial rate for 0.1 gal/minute/ft of available drawdown. Record measurements made with electrical tape on the aquifer test field measurement form.
5. Allow water level to stabilize (± 0.02 psi, ± 0.05 ft over 1 minute) using pressure transducer or electric water level measuring tape (SOP 19) for measurements.
6. Turn on pump and measure discharge rate and water level changes at the following intervals:

Time Since Pumping Started	Time Intervals
Pumped Well	
0-5 minutes	0.5 minutes
5-60 minutes	5 minutes
60-120 minutes	20 minutes
120 minutes-shutdown of the pump	60 minutes
Observation Wells	
0-15 minutes	1 minute
15-50 minutes	5 minutes
50-100 minutes	10 minutes
100 minutes-5 hours	30 minutes
5 hours-48 hours	60 minutes
48 hours-6 days	3 times/day
6 days-shutdown of the pump	1 times/day

The discharge rate is determined with a stopwatch and a graduated container. Discontinue pumping at the time indicated in the test plan or if the water level comes within 1 in. of the pump intake (whichever comes first).

7. Measure water level recovery at the same time intervals used during the drawdown phase. Discontinue measurements when water level recovers 90 percent of the drawdown.
8. Remove pumping system from well and piezometer. Replace well cap and lock well as applicable.

Standard Operating Procedure

Measurement of Turbidity Using a Portable Turbidity Meter SOP-424

The HF Scientific Turbidity meter model DRT-15CE is a portable unit that is approved by the U.S. Environmental Protection Agency for measuring the turbidity of potable water, waste water, and some other liquids. The HF meter provides a linear display of turbidity throughout all ranges, reporting results in nephelometric turbidity units (NTUs).

Operating Procedure

The procedure for measuring turbidity is as follows:

1. Clean both the Reference Standard cuvette and the sample cuvette with a lint-free wipe, such as a Kimwipe®.
2. Turn the turbidity meter switch to the "10" range, and place the Reference Standard into the optical well.
3. Turn the Reference Standard in the optical well until the reference ring notch matches the white locator pin. If the reference ring is not on the Reference Standard, turn the reference standard a full 360° and find the area with the lowest reading. Place the reference ring over the lid of the Reference Standard so that the notch will match with the locator pin.
4. Using the "Reference Adjust" arrows on the meter, adjust the display until it reads 0.02 NTU. The instrument is now calibrated and ready for use.
5. To measure turbidity in a sample, fill the sample cuvette with sample to within ½ inch of the top. Screw the cap on the cuvette and carefully clean the outside of the cell with a lint-free wipe. Place the cuvette into the optical cell.
6. Select the appropriate range for the sample (i.e., if the sample is mostly clear, take the measurement at the 0–10 NTU range setting) and take the reading from the display. If the sample is more turbid than the instrument setting, an up arrow will appear in the display, indicating that the operator should change the range to the next higher NTU range setting (i.e., 10–100 NTU).

7. Between samples, the sample cuvette should be rinsed out with deionized water. However, if the sample contains solutes that obviously do not wash out of the cuvette, follow Exponent SOP-3A to decontaminate the cuvette. It is imperative that the operator is careful not to scratch or chip the cuvettes.

Attachment A-6

**Example Groundwater
Sample Collection Form**

AR302067

GROUNDWATER SAMPLE COLLECTION FORM

Exponent

Sheet ___ of ___

Station Identification _____ Date Collected _____

Project Name _____ Contract No. _____

Purge Start Time _____ Sample Collection Start Time _____

Location _____ Weather Conditions _____

Sampling Personnel _____

Signature

Sample Collected with: ☐ Bailer ☐ Grundfos Pump ☐ Peristaltic Pump ☐ Split Barrel ☐ Other _____Made of: ☐ Stainless Steel ☐ PVC ☐ Teflon ☐ Other _____**FIELD MEASUREMENTS****PURGE DATA**

Depth to Water (Top of Casing) _____ Depth to Bottom of Well _____

Casing Diameter _____ One Casing Volume (gal) _____

Purging Data

Start Time (Well Volume 1) _____ Volume Purged (gal) _____ Turbidity (NTUs) _____

Start Time (Well Volume 2) _____ Volume Purged (gal) _____ Turbidity (NTUs) _____

Start Time (Well Volume 3) _____ Volume Purged (gal) _____ Turbidity (NTUs) _____

Time Required to Purge 3 Well Volumes _____ Total Volume Purged (gal) _____

Description (color, texture, density, turbidity, etc.) _____

FIELD PARAMETER STABILIZATION

Rep	Time	pH	S.C. (μ mhos/cm @ 25°C)	Temperature (°C)	Eh (mV)	D.O. (mg/L)	Turbidity (NTUs)
1	_____	_____	_____	_____	_____	_____	_____
2	_____	_____	_____	_____	_____	_____	_____
3	_____	_____	_____	_____	_____	_____	_____
4	_____	_____	_____	_____	_____	_____	_____
5	_____	_____	_____	_____	_____	_____	_____

Comments _____

AR302068

Attachment A-7

Standard Operating Procedure for Purging and Sampling Wells

AR302069

Introduction

This attachment has been prepared to formalize the methods by which overburden wells, wellpoints, Geoprobe[®] and viscose basin wellpoints, and bedrock wells will be purged and sampled at the Avtex site. When preparing to purge any well or wellpoint, the sampling team shall consult the appropriate decision tree in this attachment:

- Figure 1: Overburden wells, wellpoints, and Geoprobe[®] and viscose basin wellpoints
- Figure 2a: Shallow bedrock wells
- Figure 2b: Deep bedrock wells and intermediate bedrock wells with monitoring intervals less than 30 ft
- Figure 2c: Intermediate bedrock wells with monitoring intervals greater than 30 ft.

The sampling team will then follow the appropriate decision process until it results in sampling of the well. Table 1 of this attachment provides the critical information on each well to be sampled.

Table 1. Well/Wellpoint purging and sampling information, Avtex site, Front Royal, Virginia

Well ID	Depth Monitored	Well Diameter (in)	Ground Surface Elevation (ft amsl)	Monitoring Point		Total Well		Monitoring			Monitoring Depth (Open Hole or Screen)			Depth to		Minimum		Anticipated Purge/ Sampling Technique	3 Well Volume (gallons)	3 hr Purge Rate (gpm)	Inc. to change purge rate by (mL/m)
				Elevation (TOC) (ft amsl)	Depth (TOC) (ft)	Length (ft)	Interval	Monitoring Depth (Open Hole or Screen)		Water (TOC) (ft)	Total height of water column (ft)	Sample Volume Required (L)	Sample Volume (ft)								
								Top (ft b/c)	Midpoint (ft b/c)					Bottom (ft b/c)							
004	OMW	2	479.32	480.68	15.20	5	5	9.36	11.86	14.36	11.6	3.60	5.3	8.5	NA	NA	NA	NA	NA		
005	OMW	2	500.39	502.88	34.44	10	10	23.99	28.99	33.99	17.84	16.6	2.6	4.3	NA	NA	NA	NA	NA		
009	OMW	2	514.57	516.42	47.30	5	5	42.35	44.85	47.35	43.78	3.52	2.6	4.3	NA	NA	NA	NA	NA		
011	OMW	2	515.03	517.2	48.70	5	5	43.67	46.17	48.67	36.15	12.55	2.6	4.3	NA	NA	NA	NA	NA		
014	OMW	2	504.9	506.99	21.95	10	10	11.59	16.59	21.59	4.00	17.95	2.6	4.3	NA	NA	NA	NA	NA		
017	OMW	2	480	482.27	16.90	5	5	11.77	14.27	16.77	14.38	2.52	5.3	8.5	NA	NA	NA	NA	NA		
021	OMW	2	477.87	479.98	11.34	5	5	6.21	8.71	11.21	9.39	1.95	2.6	4.3	NA	NA	NA	NA	NA		
022	OMW	2	476.01	478.25	10.04	5	5	4.34	6.84	9.34	7.52	2.52	2.6	4.3	NA	NA	NA	NA	NA		
024	OMW	2	477.11	478.89	11.33	5	5	5.78	8.28	10.78	9.67	1.66	2.6	4.3	NA	NA	NA	NA	NA		
026	OMW	2	472.74	474.3	7.16	2	2	4.76	5.76	6.76	5.24	1.92	5.3	8.5	NA	NA	NA	NA	NA		
MW02	OMW	2	523.65	526.44	32.50	5	5	26.29	28.29	30.79	17.01	15.49	1.5	2.5	NA	NA	NA	NA	NA		
MW07	OMW	4	530.52	532.24	42.93	5	5	36.72	39.22	41.72	21.92	21.01	5.3	2.1	NA	NA	NA	NA	NA		
MW08	OMW	4	528.28	529.14	43.80	5	5	35.86	38.36	40.86	18.84	24.96	5.3	2.1	NA	NA	NA	NA	NA		
MW09	OMW	4	521.57	524.65	42.00	15	15	30.08	37.58	45.08	17.09	27.99	7.5	3.0	NA	NA	NA	NA	NA		
MW10	OMW	4	525.29	527.39	53.00	15	15	40.6	48.1	55.6	34.87	20.23	5.3	2.1	NA	NA	NA	NA	NA		
MW11	OMW	4	524.32	525.83	30.82	10	10	21.51	26.51	31.51	23.02	7.80	5.3	2.1	NA	NA	NA	NA	NA		
MW12	OMW	4	504.65	506.97	15.40	5	5	10.32	12.82	15.32	3.71	11.69	5.3	2.1	NA	NA	NA	NA	NA		
101	SBMW	4	549.76	551.82	50.20	22	22	27.06	38.06	49.06	7.83	42.37	9.2	3.7	Submersible	83.0	0.5	1745	174		
102	SBMW	4	561.29	563.07	49.16	20	20	26.78	36.78	46.78	22.02	27.14	7.0	2.8	Submersible	53.1	0.3	1118	112		
103	SBMW	4	522.92	525.08	42.50	16	16	27.16	35.16	43.16	3.76	38.74	7.0	2.8	Submersible	75.9	0.4	1595	160		
104	SBMW	4	478.76	481.13	45.80	20	20	27.37	37.37	47.37	12.35	33.45	4.5	1.8	Submersible	65.5	0.4	1377	138		
105	SBMW	4	495.7	498.59	51.40	11	11	43.89	49.39	54.89	24.58	26.82	6.7	2.7	Submersible	52.5	0.3	1104	110		
111	SBMW	4	515	516.45	75.80	25	25	53.45	65.95	78.45	42.80	33.00	4.5	1.8	Submersible	64.6	0.4	1359	136		
112	SBMW	4	510.26	511.58	66.00	20	20	44.32	54.32	64.32	12.61	53.39	4.5	1.8	Submersible	104.6	0.6	2198	220		
114	SBMW	4	506.28	506.85	56.77	20	20	35.57	45.57	55.57	12.11	44.66	4.5	1.8	Submersible	87.5	0.5	1839	184		
116	SBMW	4	525.65	528.24	77.75	20	20	57.59	67.59	77.59	32.65	45.10	9.8	4.0	Submersible	88.3	0.5	1857	186		
117	SBMW	4	480.5	482.21	39.04	21	21	23.71	34.21	44.71	14.13	24.91	4.5	1.8	Submersible	48.8	0.3	1026	103		
118	SBMW	4	529.36	530.72	51.00	21	21	28.36	38.86	49.36	12.82	38.18	4.5	1.8	Submersible	74.8	0.4	1572	157		
119	SBMW	4	505.65	509.25	39.18	20	20	18.6	28.6	38.6	5.76	33.42	6.7	2.7	Submersible	65.4	0.4	1376	138		
120	SBMW	4	504.09	506.19	40.90	19	19	21.1	30.6	40.1	4.01	36.89	4.5	1.8	Submersible	72.2	0.4	1519	152		
115	SBMW	4	498.12	500.9	49.47	26	26	19.78	32.78	45.78	19.51	29.96	6.7	2.7	Submersible	56.7	0.3	1234	123		
137	SBMW	6	488.89	489.29	71.15	52	52	20.4	46.4	72.4	17.93	53.22	4.5	0.8	Submersible	234.5	1.3	4931	493		
162	SBMW	6	489.39	490.04	63.02	45	45	20.65	43.15	65.65	19.38	43.64	4.525	0.8	Submersible	192.3	1.1	4043	404		
177	SBMW	6	499.01	499.41	68.50	44	44	25.4	47.4	69.4	24.52	43.98	6.7	1.2	Submersible	193.8	1.1	4075	407		
GM01A	SBMW	4	497.25	500.91	104.55	31	31	47.66	63.16	78.66	28.19	76.36	4.5	1.8	Submersible	149.5	0.8	3144	314		
MW03	SBMW	4	523.91	526.25	46.60	11	11	35.34	40.84	46.34	22.00	24.60	6.7	2.7	Submersible	48.2	0.3	1013	101		
MW04	SBMW	4	496.14	498.73	37.44	2	2	36.59	37.59	38.59	26.22	11.22	4.5	1.8	Submersible	22.0	0.1	462	46		
MW05	SBMW	4	489.7	493.18	33.00	8	8	25.48	29.48	33.48	9.09	27.39	4.5	1.8	Submersible	53.6	0.3	1128	113		

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projects\A20_Front Royal\FieldWork\Phase1_Sampling Schedule.xls Well_Construction_Larry_V

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Table 1. (cont.)

Well ID	Depth Monitored	Well Diameter (in)	Ground Surface Elevation (ft amsl)	Monitoring Point		Monitoring Interval Length (ft)	Monitoring Depth (Open Hole or Screen)		Total height of water column (ft)	Sample Volume Required (L)	Sample Volume Height (ft)	Anticipated Purge/ Sampling Technique	3 Well Volume (gallons)	3 hr Purge Rate (gpm)	Inc. to change purge rate by (mL/m)
				Elevation (ft amsl)	Depth (TOC)		Top (ft b/c)	Midpoint (ft b/c)							
PZ06	SBMW	4	476.13	478.63	25.38	11	14.5	20	25.5	5.80	19.58	Submersible	36.3	0.2	806
PZ07	SBMW	4	477.14	479.65	25.29	10	15.51	20.51	25.51	6.63	18.66	Submersible	36.5	0.2	768
PZ11	SBMW	4	476.71	479.5	80.44	28	52.79	66.79	80.79	6.52	73.92	Submersible	144.8	0.8	3044
136	IBMW	6	494.3	496.05	206.20	180	21.75	111.75	201.75	14.63	191.57	Submersible	844.1	4.7	17749
181	IBMW	6	491.16	491.66	176.00	153	20.5	97	173.5	18.32	157.68	Submersible	694.8	3.9	14609
185	IBMW	6	491.99	492.9	77.30	52	20.91	46.91	72.91	19.85	57.45	Submersible	253.1	1.4	5323
201	IBMW	4	550.27	552.39	196.85	25	162.12	174.62	187.12	12.15	174.70	Submersible	342.1	1.9	7194
202	IBMW	4	561.12	563.91	188.70	26	162.79	175.79	188.79	20.75	167.95	Submersible	328.9	1.8	6916
203	IBMW	4	523	524.23	187.50	28	161.23	175.23	189.23	3.46	184.04	Submersible	360.4	2.0	7578
205	IBMW	4	498.25	500.31	186.25	27	162.05	175.56	189.06	19.35	166.90	Submersible	326.8	1.8	6873
210	IBMW	4	478.47	480.65	102.08	22	80.18	91.18	102.18	7.70	94.38	Submersible	184.8	1.0	3866
215	IBMW	4	498.1	500.83	54.87	23	162.73	174.23	185.73	27.02	27.85	Submersible	54.5	0.3	1147
216	IBMW	4	525.67	528.67	184.40	20	163	173	183	37.03	147.37	Submersible	288.6	1.6	6068
GM02A	IBMW	4	489.85	489.85	99.21	73	28	64.5	101	14.62	85.28	Submersible	167.0	0.9	3512
GM02B	IBMW	4	490.45	490.45	159.98	63	100	131.5	163	15.85	159.35	Submersible	312.0	1.7	6562
GM04	IBMW	4	489.15	489.78	125.00	100	21.62	71.62	121.62	6.55	119.07	Submersible	233.2	1.3	4903
GM05	IBMW	4	496.05	499.38	129.50	84	45.33	87.33	129.33	26.47	103.03	Submersible	201.8	1.1	4243
GM07	IBMW	4	484.21	485.11	113.10	88	27.9	71.9	115.9	7.69	105.41	Submersible	206.4	1.1	4341
GM08	IBMW	4	524.94	526.57	132.00	82	51.63	92.63	133.63	30.29	103.34	Submersible	202.4	1.1	4255
GM09	IBMW	4	505.06	504.8	152.00	99	49.74	99.24	148.74	29.28	122.36	Submersible	239.6	1.3	5039
PW0	IBMW	6	505.2	505.92	158.00	125	33.72	96.22	158.72	26.75	131.97	Submersible	591.5	3.2	12227
PW02	IBMW	6	497.88	497.6	150.00	107	42.72	96.22	149.72	20.60	129.12	Submersible	588.9	3.2	11963
PW03	IBMW	6	498.04	497.78	157.00	124	39.74	101.74	163.74	26.46	130.28	Submersible	574.0	3.2	12070
301	DBMW	4	549.63	551.74	260.50	20	232.11	242.11	252.11	14.65	245.85	Submersible	481.4	2.7	10124
302	DBMW	4	560.87	563.22	261.40	20	232.35	242.35	252.35	22.95	238.45	Submersible	466.9	2.6	9819
303	DBMW	4	523.04	525.46	322.10	27	282.42	295.92	309.42	256.60	65.50	Submersible	128.3	0.7	2697
305	DBMW	4	499	501.63	305.40	20	282.63	292.63	302.63	22.44	282.96	Submersible	554.1	3.1	11652
315	DBMW	4	497.83	500.88	262.30	21	233.05	243.55	254.05	134.78	127.52	Submersible	249.7	1.4	5251
316	DBMW	4	525.6	528.57	260.00	20	232.97	242.97	252.97	38.60	221.40	Submersible	433.6	2.4	9117
001	OMW	2	---	---	25	10	15	20	25	10	15	Bladder	7.3	0.0	154
002	OMW	2	---	---	25	10	15	20	25	10	15	Bladder	7.3	0.0	154
GP01	OMW	1	---	---	25	5	20	22.5	25	5	20	Peristaltic/Bail	2.4	0.0	51
GP02	OMW	1	---	---	25	5	20	22.5	25	5	20	Peristaltic/Bail	2.4	0.0	51
GP03	OMW	1	---	---	25	5	20	22.5	25	5	20	Peristaltic/Bail	2.4	0.0	51
GP04	OMW	1	---	---	25	5	20	22.5	25	5	20	Peristaltic/Bail	2.4	0.0	51
GP05	OMW	1	---	---	25	5	20	22.5	25	5	20	Peristaltic/Bail	2.4	0.0	51
GP06	OMW	1	---	---	25	5	20	22.5	25	5	20	Peristaltic/Bail	2.4	0.0	51
GP07	OMW	1	---	---	25	5	20	22.5	25	5	20	Peristaltic/Bail	2.4	0.0	51

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Table 1. (cont.)

Well ID	Depth Monitored	Well Diameter (in)	Ground Surface Elevation (ft amsl)	Monitoring Point		Monitoring Interval Length (ft)	Monitoring Depth (Open Hole or Screen)			Depth to Water (TOC) 06/21/00 (ft)	Total height of water column (ft)	Sample Volume Required (L)	Minimum Sample Volume Height (ft)	Anticipated Purge/ Sampling Technique	3 Well Volume (gallons)	3 hr Purge Rate (gpm)	Inc. to change purge rate by (mL/m)
				Elevation (ft amsl)	(TOC) 06/21/00 (ft)		Top (ft b/c)	Midpoint (ft b/c)	Bottom (ft b/c)								
GP08	OMW	1	---	---	25	5	20 ^a	22.5 ^a	25 ^a	5	20	7.0	45.5	Peristalt/Bail	2.4	0.0	51
GP09	OMW	1	---	---	25	5	20 ^a	22.5 ^a	25 ^a	5	20	7.0	45.5	Peristalt/Bail	2.4	0.0	51
GP10	OMW	1	---	---	25	5	20 ^a	22.5 ^a	25 ^a	5	20	7.0	45.5	Peristalt/Bail	2.4	0.0	51
GP11	OMW	1	---	---	25	5	20 ^a	22.5 ^a	25 ^a	5	20	7.0	45.5	Peristalt/Bail	2.4	0.0	51
GP12	OMW	1	---	---	25	5	20 ^a	22.5 ^a	25 ^a	5	20	7.0	45.5	Peristalt/Bail	2.4	0.0	51
GP13	OMW	1	---	---	25	5	20 ^a	22.5 ^a	25 ^a	5	20	7.0	45.5	Peristalt/Bail	2.4	0.0	51
GP14	OMW	1	---	---	25	5	20 ^a	22.5 ^a	25 ^a	5	20	7.0	45.5	Peristalt/Bail	2.4	0.0	51
128	SBMW	4	---	---	45	10	35 ^a	40 ^a	45 ^a	10	35	7.0	2.8	Submersible	68.5	0.4	1441
129	SBMW	4	---	---	45	10	35 ^a	40 ^a	45 ^a	10	35	7.0	2.8	Submersible	68.5	0.4	1441
130	SBMW	4	---	---	45	10	35 ^a	40 ^a	45 ^a	10	35	9.2	3.7	Submersible	68.5	0.4	1441
131	SBMW	4	---	---	45	10	35 ^a	40 ^a	45 ^a	10	35	7.0	2.8	Submersible	68.5	0.4	1441
132	SBMW	4	---	---	45	10	35 ^a	40 ^a	45 ^a	10	35	6.7	2.7	Submersible	68.5	0.4	1441
232	IBMW	2	---	---	140	20	120 ^a	130 ^a	140 ^a	20	120	6.7	10.9	Submersible	56.7	0.3	1235

Note: b/c - below top of casing

N/A - not applicable

BOLD - estimated, top of borehole unknown

- based on 04/28/94 measurements

- assumed

* Monitoring depth is measured in feet below ground surface.

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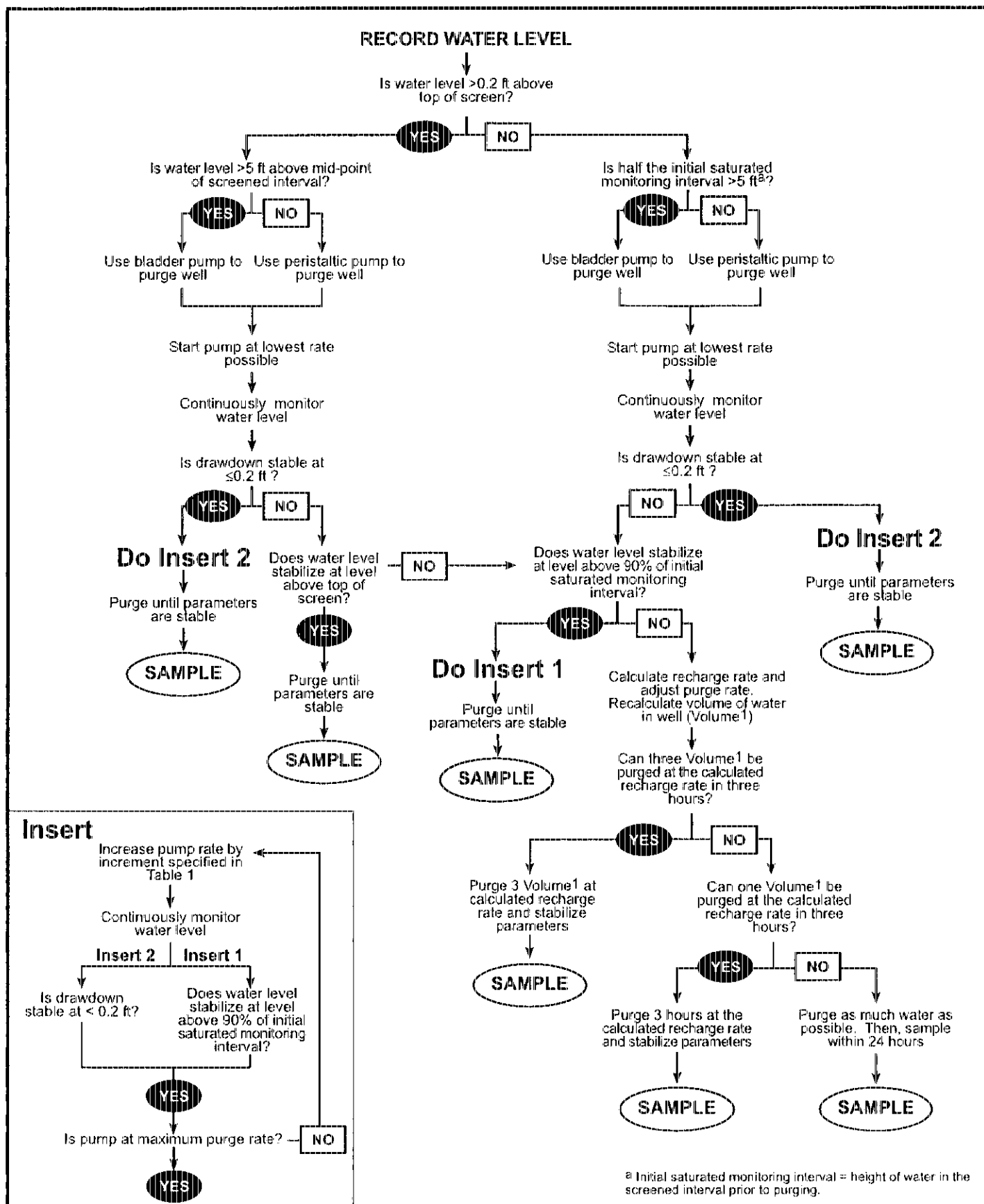


Figure 1. Decision tree for purging of overburden wells, wellpoints, Geoprobe®, and viscose basin wellpoints.

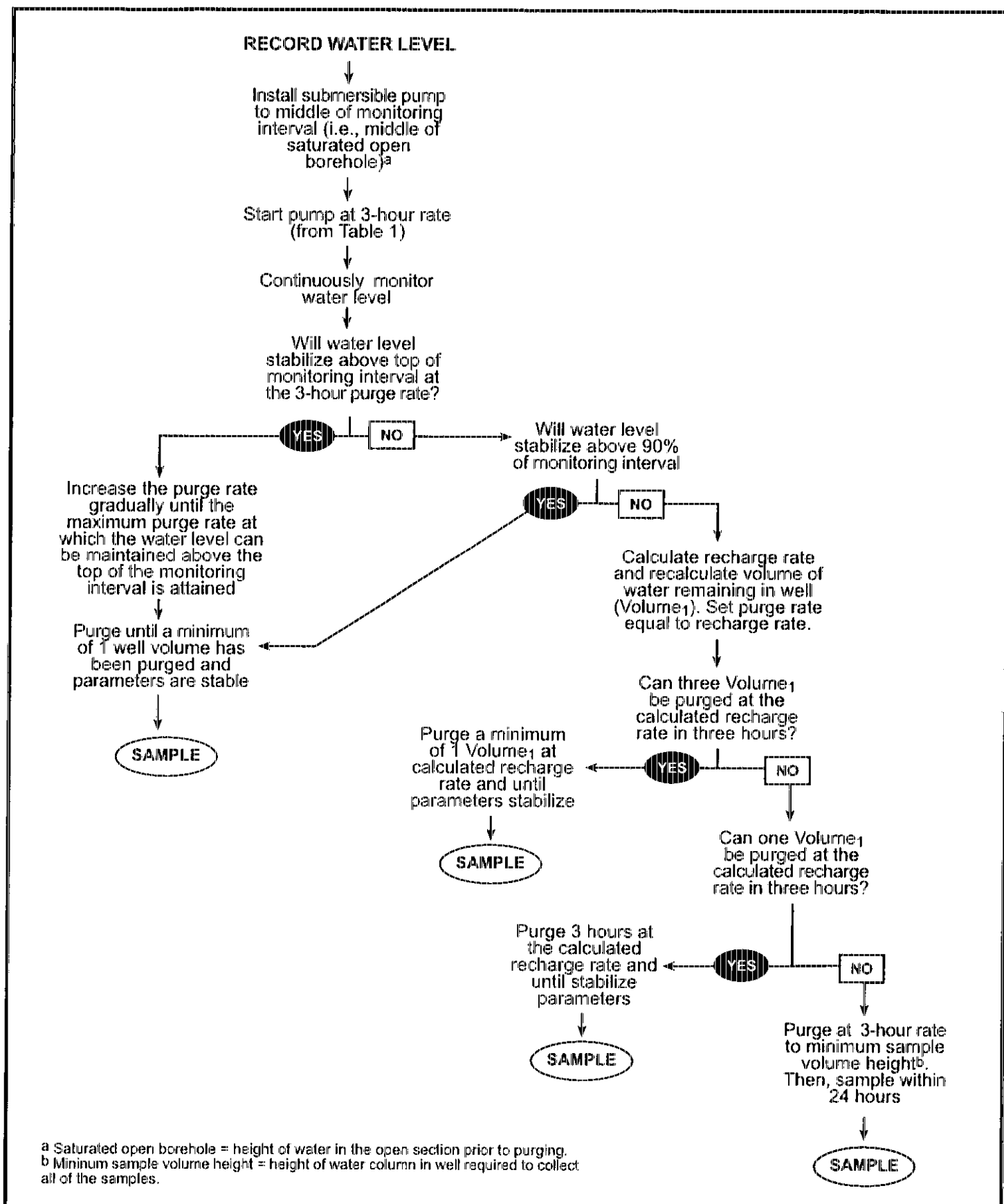


Figure 2a. Decision tree for purging of shallow bedrock wells.

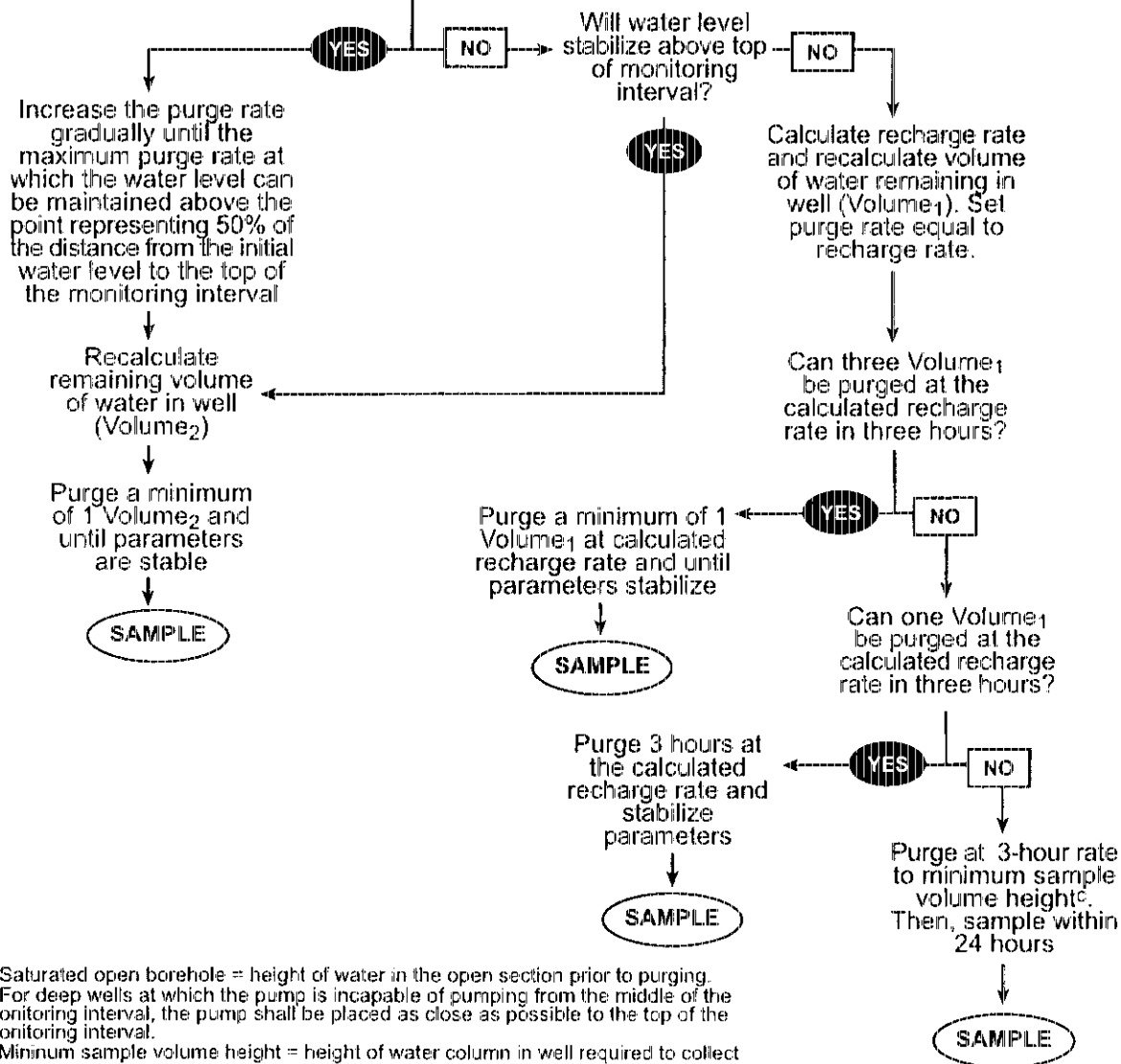
RECORD WATER LEVEL

Install submersible pump to middle of monitoring interval (i.e., middle of saturated open borehole)^{a,b}

Start pump at 3-hour rate (from Table 1)

Continuously monitor water level

Will water level stabilize above the point representing 50% of the distance between the initial water level and the top of the monitoring interval at the 3-hour purge rate?



^a Saturated open borehole = height of water in the open section prior to purging.
^b For deep wells at which the pump is incapable of pumping from the middle of the monitoring interval, the pump shall be placed as close as possible to the top of the monitoring interval.
^c Minimum sample volume height = height of water column in well required to collect all of the samples.

Figure 2b. Decision tree for purging of deep bedrock wells and intermediate bedrock wells with monitoring intervals less than 30 feet.

RECORD WATER LEVEL

↓
Install submersible pump
to middle of monitoring
interval (i.e., middle of
saturated open
borehole)^a

↓
Start pump at 3-hour rate
(from Table 1)

↓
Continuously monitor
water level

↓
Will water level
stabilize above top of
monitoring interval at
the 3-hour purge rate?

YES

NO

↓
Will water level
stabilize above 90%
of monitoring interval

YES

NO

↓
Calculate recharge rate
and recalculate volume
of water remaining in
well (Volume₁).
Set purge rate equal to
recharge rate.

↓
Can three Volume₁
be purged at the
calculated recharge
rate in three hours?

YES

NO

↓
Purge 3 Volume₁ at
calculated
recharge rate and
until parameters
stabilize

↓
SAMPLE

↓
Can one Volume₁
be purged at the
calculated recharge
rate in three hours?

YES

NO

↓
Purge 3 hours at
the calculated
recharge rate and
until parameters
stabilize

↓
SAMPLE

↓
Purge at 3-hour rate
to minimum sample
volume height^b.
Then, sample within
24 hours

↓
SAMPLE

↑
Increase the purge rate
gradually until the maximum
purge rate at which the water
level can be maintained above
the top of the monitoring
interval.

↓
Recalculate
volume of water
remaining in the
well (Volume₂)

↓
Purge a minimum
of 1 Volume₂ and
until parameters
stabilize

↓
SAMPLE

- ^a Saturated open borehole = height of water
in the open section prior to purging.
^b Minimum sample volume height = height of
water column in well required to collect
all of the samples.

Figure 2c. Decision tree for purging of intermediate bedrock wells with
monitoring intervals greater than 30 feet.

Attachment A-8

**U.S. EPA Bulletin No.
QAD023: Recommended
Procedure for Low-Flow
Purging and Sampling of
Groundwater Monitoring
Wells**

AR302078

RECOMMENDED PROCEDURE FOR LOW-FLOW PURGING AND SAMPLING OF GROUNDWATER MONITORING WELLS

1.0 OBJECTIVE AND APPLICATION

This directive provides a procedure for collection of ground-water samples in small-diameter wells with short-screened intervals using low-flow purging and sampling. While these procedures pertain to the Superfund program in Region III, they were based on recommendations presented in the EPA Ground Water Issue paper entitled "Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures". The low-flow purging and sampling method is not appropriate for use in all hydrogeologic regimes, and particular groundwater monitoring well designs may make the method unsuitable (e.g. open hole and long screen monitoring wells in bedrock and stratified sand and clay where the water bearing zones have not been characterized).

Therefore, please confer with a Region III hydrogeologist or geologist before using these procedures at a site.

2.0 BACKGROUND

Past scientific research (Barcelona et al., 1983; Nielson and Yeates, 1985) and EPA guidance have discussed sampling devices in terms of their compatibility with contaminants being sampled, and well construction, depth, and diameter. Although some sampling devices have been used in order to provide more representative groundwater samples in certain situations, most of these incorporate high-volume withdrawal techniques (i.e., in excess of the "natural" recharge rate of groundwater flow through the well screen) for both purging and sampling.

Research conducted by Puls et al. (1992), Puls and Powell (1992), and Powell and Puls (1993) has shown that high-volume purging and sampling cause significant turbidity and suspended particulate artifacts that can result in biased-high metals results. Additionally, purging can cause pressure changes and bailing can cause aeration that can strip VOCs from the sample (Pennino, 1988). The use of low-flow pumping devices (preferably dedicated) for purging and sampling minimizes both the disturbance of water in well casing and the potential for mobilization of colloidal material (Barcelona et al., 1994). Low-flow purging with maintenance of water level in the well and stabilization of indicator parameters (especially turbidity) allows collection of groundwater samples that are more representative of conditions without filtering (U.S. EPA, 1993; Backhus et al., 1993). In many cases, use of a low-flow pump to purge and sample monitoring wells decreases sampling time, reduces the need to handle large volumes of purge water and lowers the cost associated with its disposal, and allows collection of samples for

inorganic analyses without filtering. This procedure is designed to be used in conjunction with groundwater sampling and analyses for the most common types of groundwater contaminants (volatile and semi-volatile organic compounds, pesticides, PCBs and inorganic compounds).

3.0 EQUIPMENT

Adjustable rate, positive displacement pumps (e.g. low flow-rate submersible centrifugal or bladder pumps constructed of stainless steel or Teflon). Low flow-rate electrical submersible pumps are recommended because (1) they are not subject to cyclical flow/arrest and consequent potential for mobilizing fine-grained material, and (2) they may be less prone to operator error, thereby reducing potential error resulting from application by different personnel. The pump should be easily adjustable and capable of operating reliably at lower flow rates. Peristaltic pumps may be used only for inorganic sample collection. Bailers are inappropriate for use in this procedure.

Tubing: Tubing used in purging and sampling each well must be dedicated to the individual well. Once properly located, moving the pump in the well should be avoided. Consequently, the same tubing should be used for purging and sampling. Teflon or Teflon-lined polyethylene tubing must be used to collect samples for organic analysis. For samples collected for inorganic analysis, Teflon or Teflon lined polyethylene, PVC, Tygon or polyethylene tubing may be used. The tubing wall thickness should be maximized (3/8 to 1/2 inch) and the tubing length should be minimized (i.e. do not have excess tubing outside of the well).

Polyethylene sheeting and sampling gloves.

Water level measuring device, 0.01 feet accuracy, (electronic preferred for tracking water level drawdown during all pumping operations).

Flow measurement supplies (e.g. graduated cylinder and stop watch).

Interface probe, if needed.

Power source (e.g. generator, located downwind; nitrogen tank, etc). The generator should not be oversized for the pump.

In-line flow-through cell containing purge criteria parameter monitoring instruments for pH,

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turbidity, specific conductance, temperature, Eh and dissolved oxygen (DO). The in-line device should be bypassed or disconnected during sample collection.

Photoionization detector (PID), or equivalent.

Nylon stay-ties.

Decontamination supplies.

Logbook(s).

- Sample Bottles. It is recommended that preservatives are added to sample bottles prior to field activities to reduce potential error or introduction of contaminants.
- Sample preservation supplies (as required by the analytical method; see previous bullet).
- Sample tags or labels, chain of custody.
- Well construction data, location map, field data from last sampling event.
- Approved Field Sampling Plan/QA Project Plan.

4.0 PRELIMINARY SITE ACTIVITIES

1) Check the condition of the monitoring well for damage and evidence of tampering, and record pertinent observations.

2) In order to maintain a clean work area, lay out a sheet of polyethylene to place sampling and monitoring equipment.

3) Remove well cap and measure VOCs at the rim of the well with a PID or FID instrument and record the reading in the field logbook.

4) If the well casing does not have a reference point (usually a V-cut or indelible mark in the well casing) make one.

5) Measure and record the depth to water (to 0.01 feet) in all wells to be sampled before any purging begins. Care should be taken to minimize disturbance to the water column and to any

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particulate attached to the sides or at the bottom of the well. Consequently, in order to avoid disturbing any accumulated sediment and to prevent mixing of stagnant water with water in the screened interval, the total depth of a well should be measured well in advance (one to two weeks) of purging and sampling or after sampling is completed. Obtain depth to bottom of well information from the well construction log and calculate standing water volume as: depth of water column times cross-sectional area of the well.

6) For wells where an Light Non-aqueous Phase Liquid (LNAPL) has been detected, a stilling tube should be inserted into the well prior to purging. Refer to Section 7.2.4 of EPA (1992) for the procedure to follow. If the wells are constructed so that DNAPLs could accumulate, their detection and /or sampling should occur, at a minimum, a week before groundwater purging and sampling. Measurement and sampling of potential DNAPL should be conducted as a separate event to minimize disturbance of any sediments which have accumulated in the bottom of the well. A double check valve, bottom loading bailer is recommended for sampling. Light non-aqueous phase liquid (LNAPL) measurement may be conducted (with an interface probe), with care to avoid disturbance of the water column within the well.

5.0 PURGING AND SAMPLING PROCEDURES

The following describes the procedure for the low-flow purging and sampling method. Equipment calibration, logbook documentation, sample bottle filling and preservation, and shipping will be conducted in accordance with the site-specific Quality Assurance Project Plan (QAPjP). Personal protective equipment will be donned in accordance with the requirements of the site-specific Health and Safety Plan. Wells should be sampled in the order of least contaminated to most contaminated.

1) Attach and secure the polyethylene tubing to the low-flow pump. As the pump is slowly lowered into the well, secure the safety drop cable, tubing, and electrical lines to each other using nylon stay-ties.

2) Pump, safety cable, tubing and electrical lines should be lowered slowly into the well to a depth corresponding to the center of the saturated screen section of the well, or at a location determined to either be a preferential flow path or zone where contamination is present. The pump intake should be kept above the bottom of the well to prevent mobilization of any sediment or DNAPL present in the bottom of the well. It is recommended that the pump be placed in the well 12 to (preferably) 48 hours prior to purging/sampling to minimize the effects of turbidity and mixing in the well from introducing the pump.

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3) Measure the water level again with the pump in the well before starting the pump. Start the pump at the lowest rate possible (100 mL/min) while measuring the drawdown continuously. The pumping can only be increased as long as there is no drawdown. Avoid surging. Observe air bubbles displaced from discharge tube to assess progress of steady pumping until water arrives at the surface. The pumping rate should cause little or no water level drawdown in the well (less than 0.2 ft) and the water level should stabilize. Water level measurements should be made continuously. Precautions should be taken to avoid pump suction loss or air entrainment. Pumping rates should, if needed, be reduced to the minimum capabilities of the pump to avoid pumping the well dry and ensure stabilization of indicator parameters. If the recharge rate of the well is very low, purging should be interrupted so as not to cause the drawdown within the well to advance below the pump intake but the operator should attempt to maintain a steady flow rate with the pump to the extent practicable. In these low-yielding wells, where 100 mL/min exceeds the entrance rate of groundwater into the well, it is important to avoid dewatering the well screen interval. In these cases, the pump should remain in place and the water level should be allowed to recover repeatedly until there is sufficient volume in the well to permit collection of samples. An alternative means of sample collection may be necessary under these conditions.

4) While purging the well, monitoring of in-line water quality indicator parameters should include turbidity, specific conductance, pH, dissolved oxygen (DO), temperature and redox potential (Eh) which must be collected every three to five minutes until all of the parameters have stabilized. Stabilization is achieved when three successive readings are within ± 0.1 for pH, $\pm 3\%$ for conductivity and temperature, ± 10 mv for redox potential (Eh), and $\pm 10\%$ for turbidity and DO. A minimum subset of these parameters that can be used to determine stabilization during purging in this procedure are pH, specific conductivity and turbidity or DO. Turbidity and DO are typically the last parameters to stabilize. If the parameters have stabilized, but the turbidity is not in the range of 5-10 NTU, then follow step 6.

5) Once stabilization has been documented, VOC and gas sensitive (e.g. Fe^{+2} , CH_4 , $\text{H}_2\text{S}/\text{HS}$) parameter samples should be immediately collected first and directly into pre-preserved sample containers. All sample containers should be filled by allowing the pump discharge to flow gently down the inside of the container with minimal turbulence.

Samples requiring pH adjustment should have their pH checked to assure that the proper pH has been obtained. For VOC samples, this will require that a test sample be collected to determine the amount of preservative required to be added to the sample containers prior to sampling.

6) If the turbidity measurements do not approach the range of that of natural groundwater (10 NTU), both filtered and unfiltered samples should be collected for metals analysis. Filtered metal samples are to be collected with an in-line filter. A high capacity, in-line 0.45 micron

particulate filter must be pre-rinsed according to the manufacturer's recommendations, or with approximately 1 liter of groundwater following purging and prior to sampling. After the sample is filtered it must be preserved immediately.

7) As each sample is collected, the sample should be labeled as defined in the QAPjP. All samples should be placed into a cooler with proper temperature control as outlined in the QAPjP.

After collection of the samples, the tubing from the pump should be properly discarded or dedicated to the well for re-sampling (by hanging the tubing inside the well).

8) Measure and record well total depth.

9) Secure the well (close and lock it up).

6.0 REFERENCES

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U.S. Environmental Protection Agency. 1992. RCRA Ground-Water Monitoring: Draft Technical Guidance. EPA/530-R-93-001.

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Attachment A-9

**Example Sample Tag, Sample
Seal, and Chain of Custody
Record/Sample Analysis
Request Form**

AR302086

Page _____ of _____

HF₂ component

Relinquished by: _____	Date/Time: _____	Received by: _____	Date/Time: _____
(Signature)		(Signature)	
Relinquished by: _____	Date/Time: _____	Received by: _____	Date/Time: _____
(Signature)		(Signature)	

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Exponent™	SAMPLE NO.	
	SITE NAME	
	DATE	TIME
	SAMPLER	PRESERVATIVE
	TAG NO. 30101	

Exponent™ OFFICIAL SAMPLE SEAL	SAMPLE NO.	DATE
	SIGNATURE	
	PRINT NAME AND TITLE	

AR302088

Attachment A-10

X-Ray Diffraction Analysis

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X-Ray Diffraction Analysis

Solid material collected upon filtration of the fluids from the carbon disulfide hydrolysis studies will be evaluated by x-ray diffraction (XRD) to identify any crystalline compounds (particularly metal sulfides) that precipitated during the hydrolysis experiment. Powder XRD analysis will be conducted using a Scintag PAD 5 x-ray diffractometer at the Department of Geological Sciences, University of Colorado at Boulder, according to the following procedure.

The sample will be lightly crushed in a clean mortar and pestle. The resultant powder will be packed into a Lucite sample holder to create a packed powder mount. The Scintag PAD 5 x-ray diffractometer houses an x-ray tube with a copper target, and the rotating goniometer is calibrated against an alpha-quartz standard on a weekly basis. Diffraction data on the sample will be collected from 2 to 60 ° θ at a scanning speed of 1 ° θ /min. The instrument computer will compare the diffraction pattern collected on the sample against the known powder pattern library maintained by the International Center for Diffraction Data (ICDD). The search-match program can successfully identify up to seven components in an unknown pattern. The analyst will then provide visual confirmation of any matches between the sample and potential sample components identified by the instrument computer. The intensity of the diffraction peaks will be used to estimate the relative abundance of any mineral phases identified in the sample.

Attachment A-11

Scope of Work for ERH Testing

AR302091

Scope of Work:

Feasibility Testing for Electrical Resistance Heating

Exponent will obtain representative, relatively undisturbed, 1- or 2-inch-diameter, waste material core samples. Samples will be 12 inches long, sealed and capped in moisture-proof liners.

Samples will be collected from three depths at a representative location in each viscose basin. Target depths are 4 ft (middle of unsaturated zone, high CS₂ level), 8 ft (bottom of unsaturated zone, possible capillary fringe zone, high CS₂ level), and 16 ft (saturated zone, high CS₂ level). Actual sample depths will be field determined by Exponent depending on site conditions.

Exponent will obtain three representative grab samples of water, one from each sample location, collected from below the water table. Samples will be collected in 1-L plastic containers with no preservatives.

Exponent will measure the actual undisturbed shallow groundwater temperature (or determine the annual average air temperature at site ground level).

Exponent will ship the nine waste and three water samples to AHA's Calgary lab.

AHA will test nine waste samples for static electrical conductivity (EC) at lab temperature, and one for dynamic electrical conductivity, to determine EC as a function of temperature.

AHA will test three water samples for static electrical conductivity at room temperature, 40 °C, and 80 °C.

AHA will test two of the waste samples for static thermal conductivity at room temperature.

If air and/or water permeability, bulk density, and porosity have already been characterized for the site, Exponent will provide those data. If these parameters have not been determined, Exponent will obtain six additional waste material core samples from similar depths, to be tested for these parameters by Exponent.

AHA will perform preliminary modeling of the test area to determine vapor removal potential, power requirements, appropriate well and electrode spacing, and approximate time for test-area cleanup. This effort will provide an initial evaluation as to whether this technology is technically feasible and cost effective, and will provide data for system design.

Preparation of a Remedial Design Cost Estimate

Exponent will provide site characterization data, including:

- Map(s), preferably in AutoCAD R14, showing the areas to be remediated and the power line(s) adjacent to that area.
- Elevation contours for base of waste, top of waste, and water table.
- Existing groundwater remediation system (if any).
- Nature and hydraulic conductivity of material underlying waste.

Exponent will locate the desired pilot test area and indicate its approximate size (e.g., 30x60 ft).

Exponent will determine the desired remediation time for the entire project (e.g., 3 years).

Exponent will determine the locations of buried underground electric cables, telecom lines, or metal conductors (e.g., gas or water pipes) in the areas to be remediated, if any.

Exponent will determine the available power supply parameters as follows:

- Name of power company, and name and telephone number of contact person
- Distance from power line to test area
- Power line voltage and available amperage
- Service configuration (delta, Y, etc.)
- An example of a current commercial power contract, if available.

Exponent will provide costs for preparing drilling access, drilling 10-inch borings to the base of the waste for electrode installation, and a rig hourly rate, including crew, for electrode installation. Electrodes are approximately 25 ft long and weigh 200 lb.

Exponent will indicate the availability of clean water supply for electrode cooling (approx. 4 gpm for the test area), and options for disposal of cooling water (approx. 200 °F) and dewatering product (probably high CS₂). If no onsite water treatment facilities are available for the pilot test, AHA will add this element to the cost estimate.

AHA will contact the power company to determine the cost of providing power to the test area.

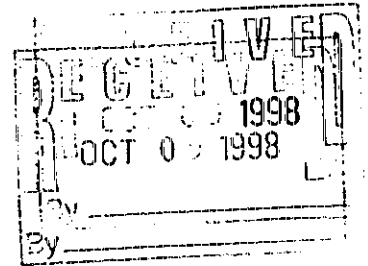
AHA will prepare a cost estimate for performing a pilot test in the test area. This estimate will include a breakdown of capital equipment (including power supply, controller, electrodes, electrode cooling system, matrix dewatering, aqueous-phase treatment, vacuum system, and vapor-phase treatment), installation, and pilot operations/reporting.

AHA will also prepare a preliminary cost estimate for remediating the entire area in the desired time. The estimate will be presented in dollars per calendar year (\$/c.y.). This estimate will be subject to modification in light of pilot test results, ongoing characterization, and ongoing operational experience.



Applied Hydrology Associates, Inc.

1200 S. Parker Rd., Suite 100 Denver, CO 80231 - (303) 873-0164 - Fax (303) 873-6110



Mike Ruby
Exponent
4940 Pearl East Circle, Suite 300
Boulder
CO 80301

October 7, 1998

Subject: In-Situ Thermal Desorption by Electrical Resistance Soil Heating

Dear Mike:

In our 10/1/98 phone conversation you indicated that Exponent would like to pursue a joint venture with Applied Hydrology Associates, Inc. (AHA). In this joint venture, a pilot section of a semi-solid, viscose waste pond would be remediated using in-situ thermal desorption (ISTD) of carbon disulfide using electrical resistance soil heating (ERSH).

Carbon disulfide has a vapor pressure (297 mm) four times that of benzene, and boils at 116 °F (47 °C). As a rule of thumb, vapor pressure doubles for each 10 degrees C increase in temperature. Therefore, increasing temperature would likely be effective in liberating CS₂ from the matrix, depending, of course, on the permeability of the viscose waste. You described it as having permeability like tight clay. It may be appropriate to apply a vacuum to the pond surface or to vapor extraction "wells" in the waste.

Because of the hazardous nature of CS₂, any heating project should be designed to minimize the risk of personnel exposure, fire, or explosion.

Before planning any pilot project, it is essential to perform tests on several undisturbed waste core samples (or in situ) to determine the feasibility of ERSH. These tests include density, electrical resistivity, thermal conductivity, and air permeability. Samples should be collected to the base of the waste, both above and below the "water table", to allow variations with depth and moisture content to be determined. Determination of water permeability, porosity, and compressive/tensile strength would also be very useful for design purposes.

AHA is in a strategic alliance with McMillan-McGee Canada Corp. (MM), of Calgary, Alberta to offer ISTD services using ERSH. The president of MM, Bruce McGee, designed the ISTD system for the Lawrence Livermore National Laboratory (LLNL) demonstration project, which remediated 800 barrels of gasoline from a sequence of alternating clays and sands. Bruce is a former student of Fred Vermeulen (University of Alberta), who pioneered electrical resistance heating for tar sands and heavy oils in Canada. Dr. Vermeulen is an advisor to AHA-MM. MM has worked with AHA since October 1997 to develop and operate an electrical resistance soil remediation program for the Turtle Bayou Superfund site in Liberty County, Texas, for ARCO Chemical Company (ACC). MM designed and built the electrodes, power supply, and power control system.

AHA provided design input at several key stages, including site characterization, SVE system design, soil parameter testing, electrode testing, power supply testing, control system testing, temperature control during operations, and overall heating operations.

System design uses TETRAD, a multi-phase 3-D electricity, heat, and vapor flow simulation model (the model costs about \$100,000). The original TETRAD simulates single-phase power (positive and negative electrodes) only. Dr. McGee has upgraded the model to simulate 3-phase power (three phase electrodes and one or more neutral electrode) which has a slightly different current distribution.

Electrical resistance soil heating plays an essential part in remediating soil "hot spots" at the Turtle Bayou site. The most significant geological features of the site are low-permeability soils that overlie a shallow aquifer. The Beaumont clay ($K_{\text{hydraulic}} = 1 \times 10^{-7}$ to 1×10^{-6} cm/sec) could be taken as an analog of the low-permeability viscose waste at your candidate site. Chemicals (mainly benzene) have soaked into these clay soils and could gradually leach into the underlying groundwater. The low clay permeability means that conventional remediation techniques, using water or soil vapor as a chemical carrier, are not very effective. However, soil heating by electrical resistance has greatly enhanced remediation efforts through the following synergistic effects:

- (1) heating significantly increases the vapor pressure of benzene, causing benzene mass to enter the vapor phase;
- (2) soil moisture (which is high in clays) is converted to steam, setting up pressure gradients which speed vapor migration;
- (3) removal of soil moisture causes the clays to shrink and crack, allowing faster vapor transport and removal.

In conjunction with the existing soil vapor extraction system (about 4 scfm), ERSH resulted in the areas of the test site where it was applied reaching cleanup criteria in 2-½ months, as demonstrated by soil borings. Without soil heating, it would probably have taken 2-3 years. Soil heating resulted in considerable cost savings to the project. Average soil temperature was raised from 71 °F to 116 °F (45 deg F or 25 deg C) in 71 heating days, at an electricity cost of \$0.13/deg C/m³. Soil temperatures measured in the field (see attached figure) corresponded almost exactly with the TETRAD-predicted temperature distribution.

Soil heating was applied at a depth of 12-17 feet (10-15 feet below the original ground surface). Excluding one anomalous result (to be re-tested), benzene concentrations reduced by an average of 95.7% of the original concentration. By depth, benzene reduction was as follows:

Depth	Reduction	Comments
8-10'	92.9%	2-4' above electrode
10-12'	95.7%	0-2' above electrode
12-14'	98.6%	top 2' of electrode

Benzene reduction is expected to be symmetrical across the electrode in synch with the temperature and current density distribution. Note that heating can be "focused" with ERSH (and RF heating) whereas direct heating radiates spherically.

To date, contaminated low-permeability media have posed an almost intractable problem for remediation. The most common approach has been to excavate and replace with clean soils, or to cap and contain within slurry walls. Electrical resistance soil heating provides an alternative that minimizes site disruption and ecology, while still effectively safeguarding the public health and the environment.

AR302096

At Turtle Bayou, alternative soil heating technologies were considered and rejected. Hot air, steam, or hot water injection are impractical due to the low clay permeability. Direct heating (e.g., Terratherm) would require a much larger number of heating wells (approximately 6 times more) and would likely be less economic. Higher temperatures can be achieved with direct heating, but these temperatures are not necessary for remediating typical volatile organic compounds that are found at most Superfund sites in the United States. Radio frequency (microwave or RF) heating is still at a very experimental stage and has licensing and health issues. Electrical resistance soil heating does not have these drawbacks. In addition, it can be focused on specific soil depth intervals for greater efficiency.

Pacific Northwestern Laboratories (PNL) have patented the six-phase ERSH system, which they claim provides more even heating. It requires a fairly large (probably expensive) phase-shifting power supply and twice as much control. We use standard three-phase power with weekly alternating of phase and neutral, which provides a fairly even heating pattern at lower cost.

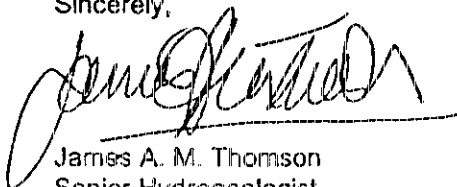
We do, however, use a sophisticated programmable power control system, which was developed specially for the Turtle Bayou project. This system automatically tests for changes in soil resistance 12 times per second and adjusts the applied voltage to maintain current within power supply specifications. It provides soft start and soft shutdown (to avoid arcing and excess starting current draw), and can be programmed to control electrode cooling and adjust power supply limits to cabinet temperature (most power supplies de-rate at high ambient temperatures). It is controlled by an EPROM, which can be reprogrammed to adjust for site-specific factors (e.g., enthusiastic operators setting the amperage above the capacity of the equipment).

The technique is best when used in combination with soil vapor extraction and surface vapor treatment (e.g., thermal oxidation), a commonly used (and relatively inexpensive) remediation technology.

ERSH is not advisable if there are buried metal conductors in the volume to be treated. ERSH could also affect telecom transmission if applied to material in direct contact with telecom lines.

AHA and MMCC would like to work with Exponent on developing a pilot project for the viscose waste pond. To preserve some proprietary components of our work, our preference would be to offer a turnkey bid and operation under Exponent's overall project management. However, other arrangements are possible. Please review the information provided and call me at 303-873-0164 (extension 107) if you would like to discuss the project further. I look forward to hearing from you.

Sincerely,

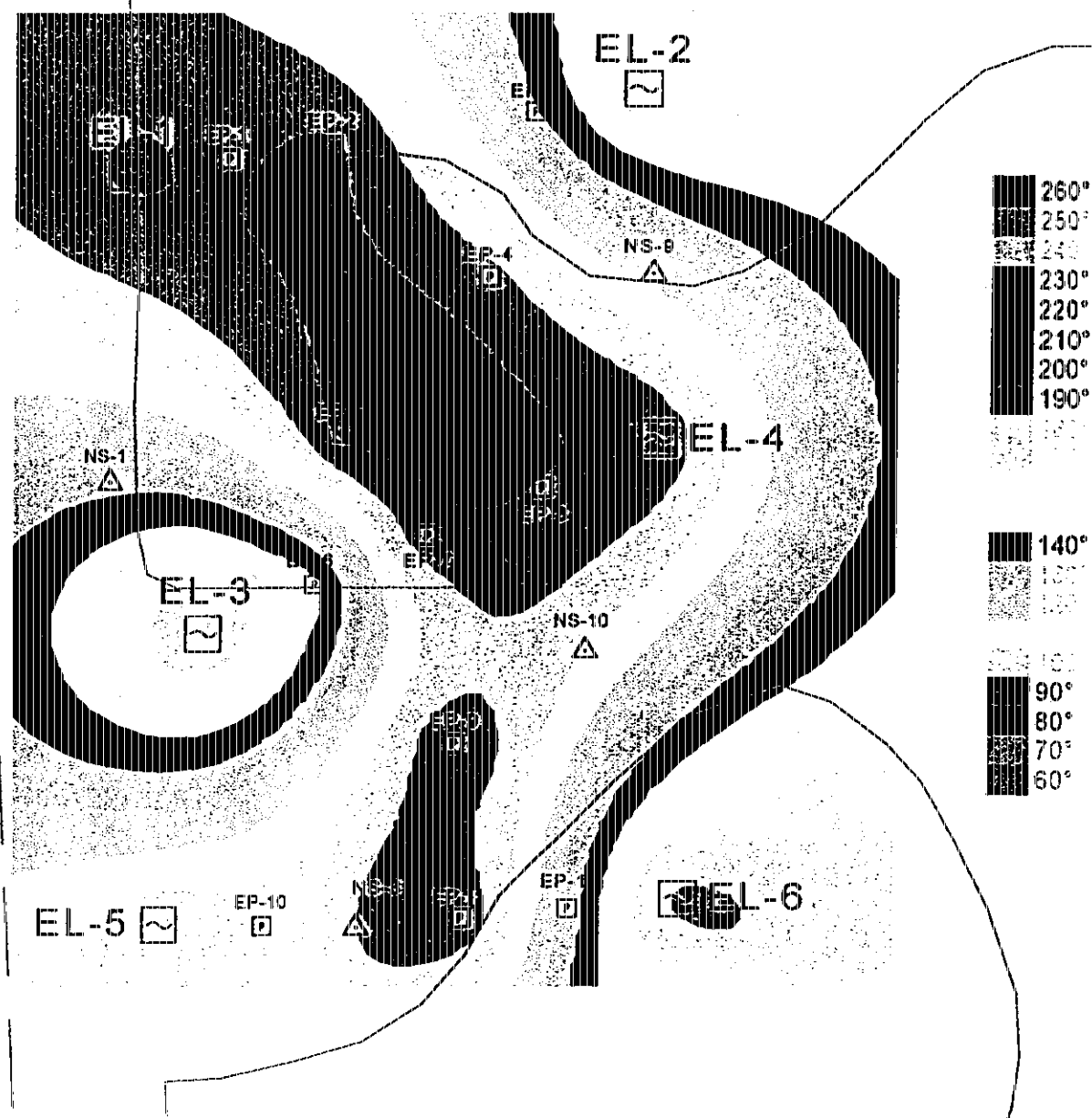


James A. M. Thomson
Senior Hydrogeologist
Partner, Applied Hydrology Associates

Attachment:

Soil Temperature contours at E-17 test area, Turtle Bayou Superfund site (initially 71 °F)

AR302097



LEGEND

- △ SOIL VAPOR EXTRACTION WELL
- ELECTRODE WELL
- THERMOCOUPLE PROBE

10' 0 10'
SCALE IN FEET

ARGO CHEMICAL COMPANY
TURTLE BAYOU PROJECT
LIBERTY, TEXAS

EASEMENT AREA, E-17 1STD AREA

FIGURE 7-22
SOIL TEMPERATURE (°F)
15' BELOW GROUND SURFACE
SEPTEMBER 29, 1998

DESIGN	JMT	DATE	10/2/98	FILE REFERENCE
PLUM	OBS	SCALE	As Shown	SOIL_TEMP.DWG
REVISION	DATE	BY	DESCRIPTION	REVISION
				35-6

AR302098

Attachment A-12

Free and Bound Carbon Disulfide Testing

AR302099

Free and Bound Carbon Disulfide Testing

As discussed in the Feasibility Study (FS) Work Plan, carbon disulfide may be present in the waste viscose both as carbon disulfide dissolved in pore water (i.e., “free” carbon disulfide) or as carbon disulfide bound to cellulose as cellulose xanthate—referred to herein as “bound” or “potential” carbon disulfide. The free and bound carbon disulfide testing described here will determine the concentration of carbon disulfide present as each of these two forms in the waste viscose.

This determination will be made using a three-step sequential extraction procedure. The first step in the sequential extraction will involve the leaching of 4 g of the sample of waste viscose in 10 mL of methanol for 2 minutes, followed by analysis of carbon disulfide using purge-and-trap (Method 5030B) and GC/MS (Method 8260B) methods. This is the standard approach for determining the concentration of carbon disulfide in solid samples. The second step in this procedure will involve particle size reduction of the 4-g waste viscose sample (from the above analysis) using a small coffee grinder (or similar device), followed by re-extraction in 10 mL of methanol for 2 minutes. This extract will also be analyzed for CS₂ concentration by purge and trap (Method 5030A) and GC/MS (Method 8260B). The third, and final, step in this procedure will involve solubilizing the 4-g sample in 10 mL of concentrated sulfuric acid (in a sealed Teflon bomb) heated to 160°F, and analysis of this extract for CS₂ concentration using the same analytical methods as cited above for the first two extracts.

Attachment A-13

**Fourier Transform Infrared
Spectroscopy Analysis**

AR302101

Fourier Transform Infrared Spectroscopy Analysis

Before and after the extraction procedure to quantify the amounts of free and bound carbon disulfide in the waste viscose (See Attachment 11), samples of the pre- and post-extracted material will be analyzed by Fourier transform infrared spectroscopy (FTIR) to provide a semi-quantitative analysis of the relative abundance of carbon disulfide bound to the cellulose matrix (i.e., present as cellulose xanthate). These analyses will be conducted by R.J. Lee Group, Inc. in Monroeville, Pennsylvania.

Three subsamples of the waste viscose (one from each of viscose basins 9, 10, and 11) that will be subjected to the free and bound carbon disulfide extraction will be submitted to R.J. Lee Group for FTIR analysis. Each sample will be sheared in a coffee grinder, and the resulting particulate will be mixed with 1 percent potassium bromide and mounted on three separate slides for analysis. Diffuse reflection spectra will be collected for each slide mount using a Perkin Elmer 1710 FTIR. The spectroscopist will examine the spectra for peaks that indicate the presence of cellulose xanthate (i.e., the bond between dithiocarbonic acid and cellulose), and the carbon-sulfur bond of carbon disulfide. Comparison of the three analyses for each of the three samples will provide a measure of the heterogeneity of the cellulose xanthate remaining in the waste viscose. Subsequent to the extraction procedure for removing the bound carbon disulfide from these three samples of waste viscose, the FTIR analyses will be repeated to determine whether all of the cellulose xanthate has been degraded.

Attachment A-14

**Waste Viscose Hydroxide
Liberation Tests**

AR302103

1. *Journal of the American Medical Association*, 1997; 277: 1039-1043.